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BASIC REQUIREMENTS FOR MANUSCRIPTS

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VARIABLE-ANGLE LAUNCHER: A NAVAL ORDNANCE TESTING FACILITY

John L. Cox,* A.M. ASCE
(Proc. Paper 1339)

FOREWORD

The design and construction of the U. S. Naval Ordnance Test Station's "Variable-Angle Launcher"—a unique $2,000,000 test facility at the Station's Morris Dam Torpedo Range near Azusa, California—is described in Proceedings Papers 1339 through 1343. Designed to launch various types of projectiles into the water under controlled conditions at high velocities and variable entry angles, the variable-angle launcher permits the detailed study of projectile water-entry performance. It has served as a valuable tool in developing improved air-launched torpedoes which can be released by aircraft at high altitudes and at high release speeds.

The launcher consists of a 22 1/2-in. torpedo-launching tube, 300 ft. long, mounted on a movable 300-ft., all-welded, steel bridge. The upper end of the bridge is supported on a welded structural steel carriage which rides on rails up and down the 45° slope of a peninsula jutting into Morris Dam Reservoir. The lower end of the launcher bridge is supported by a second, transverse bridge 95 ft. long, which rests on two steel barges floating in the water. The weight of the launcher and carriage is balanced by a 600-ton counterweight car which rides on rails up and down the back slope of the peninsula. The elevation angle can be varied between 10° and 40° by moving the upper end up or down the tracks on the 45° slope. The launcher can also be rotated in azimuth by adjusting the position of the barges and transverse bridge.

Projectiles are launched at velocities up to 800 ft. per sec. by means of a compressed air system. The compressed air, at 1,000 lb. per sq. in., is contained in a 500-cu.-ft., all-welded, air flask, and is released into the launcher tube by means of a quick-acting 22 1/2-in. sleeve which opens in 0.10 sec. A complex electronic system controls the launching process. Elaborate instrumentation—photographic, acoustic, and electronic—provides information on the position, attitude, velocities, and accelerations of projectiles during launching and water entry.

Note: Discussion open until January 1, 1958. Paper 1339 is part of the copyrighted Journal of the Construction Division of the American Society of Civil Engineers, Vol. 83, No. CO 1, August, 1957.

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Proceedings Paper 1339 presents the need for a research facility of this sort, outlines the planning of the structure, and describes the functions and characteristics of the structural elements. Proceedings Paper 1340 describes the extensive foundation treatment required and the design of the concrete structures. Proceedings Paper 1341 presents a description of the steel structures, including the 300-ft. span, all-welded, launcher bridge—longest all-welded bridge span in the United States. Proceedings Paper 1342 discusses the mechanical and electrical features of the launcher, including the projectile-launching equipment, handling and transport equipment, operating equipment used to change the launcher angle, and test instrumentation. Proceedings Paper 1343 summarizes the actual construction of the facility, including some unusual solutions to the construction problems.

In order to accomplish the development of naval ordnance weapons, particularly the aircraft torpedo, the Navy Department sponsored the construction of an unusual structure as a facility of the U. S. Naval Ordnance Test Station at the Morris Dam Torpedo Range, California. This device permits the launching of projectiles at high velocity into water for the purpose of studying their water-entry performance at variable entry angles (Fig. 1). This paper is the first of a series of five which will deal principally with the design of this variable-angle launcher. As an introduction, the first paper presents the need for a research tool of this sort, a brief outline of the planning of the structure, and a description of the functions and characteristics of the structural elements. Subsequent papers will describe in more detail the concrete structures including the foundation investigation and treatment, the all-welded steel structures and the mechanical operating equipment. A final paper will describe the construction methods and features of interest encountered during construction.

During the period between World War I and World War II, very limited experimental facilities were available for aircraft torpedo development work and little experience had been accumulated. Combat use showed that erratic behavior and structural deficiencies required the imposition of very conservative tactical limitations on altitude and speed of release. These tactical limitations were necessary to increase the effectiveness of the weapon but the losses and damage to our aircraft due to enemy action were very serious. It was evident that research and development work on the aircraft torpedo was necessary.

The problems to be solved were twofold: (1) problems related to the behavior of projectiles during and subsequent to water entry; and (2) problems related to the structural strength of projectiles and of apparatus and equipment mounted within the projectile. In order to investigate these problems, facilities were required with which proper experimentation and development could be made. The requirements for quantitative research on torpedo launching were considered to be as follows:

1. Numerous launchings must be made under identical conditions as far as major variables are concerned.
2. It must be possible to change the variables singly and in combination throughout the ranges which are to be encountered in service conditions.
3. It must be possible to measure the launching conditions actually attained, so that there can be no doubt as to the values of the variables.
4. It must be possible to determine just what happens to the projectile after it has been launched under known conditions.

A consideration of these requirements indicated that a fixed-location launcher possessed numerous advantages over aircraft drops. Specifically the advantages were three-fold:

1. Knowledge of exact projectile entry point allows permanent installation of photographic equipment, trajectory nets, hydrophone and sonobuoy ranges, and other instrumentation required for completely recording entry and subsequent behavior.
2. The orientation of projectiles can be varied and controlled with a fixed-location launcher.
3. Launching speeds can be attained which equal the speed of service aircraft permitting the development of projectiles to parallel the advancement of aircraft speeds.

During World War II a fixed-angle, fixed-location, torpedo launcher was constructed by the California Institute of Technology at Morris Dam in the San Gabriel Canyon, California. This work was part of the nation-wide program of the Office of Scientific Research and Development. Since the war, the program has been continued under the direction of the Bureau of Ordnance through the Naval Ordnance Test Station, China Lake, California. The Metropolitan Water District of Southern California maintains the dam and reservoir which is used for conservation and flood-control. The torpedo station is on a peninsula jutting into the lake formed by Morris Dam. Figure 2 is an aerial photograph of the torpedo station showing the launchers and other facilities. The fixed-angle launcher is directed northward from the peninsula and consists of a 300-ft. long tube at 19 degrees with the horizontal through which, by means of compressed air, full-scale torpedoes can be launched.

The accomplishments of this station during the war were made evident by reports of greatly improved operating characteristics from field test and combat areas. The morale of the pilots was greatly improved by the restoration of confidence in the torpedo and the resulting use of the weapon had decisive effects against the enemy in the Pacific area during World War II.

While the value of research performed with the fixed-angle launcher was considerable, the desirability of a variable-angle launching device for extension of hydrodynamic research had been apparent for some time. A systematic study of the behavior of missiles of various shapes as they entered the water would yield the design information needed to develop torpedo bodies required to enter the water at high velocity. Furthermore, the impulsive loading of the torpedo shell which had frequently led to structural failure such as that illustrated in Fig. 3 could be studied in detail. Entry angle had proved to be the most important single variable in the behavior of projectiles during and subsequent to entry. With a device adjustable to small angles, studies of flat entry and ricochet would be possible. Other advantages of a new structure included adaptability to varying lake elevations, the possibility of providing launching devices of various sizes and types, and the opportunity to design for much higher launching speeds than were possible with the former structure.

The planning and design of the Variable-Angle Launcher was commenced during the latter part of 1945. The first step in the planning involved the preparation of specifications detailing the desired performance characteristics. The basic requirement for the device was that a projectile as large as a full-scale torpedo could be propelled into the water at a velocity and at entry angles within the range experienced in aircraft drops. This consideration

determined that the water-entry angle should be variable within the range from 10 to 40 degrees.

The air flight distance, or distance of travel through which the torpedo is unsupported and unguided, should be small enough to avoid inducing an uncontrolled amount of pitch or yaw, and large enough to avoid any spurious effects from the launching method and equipment. If controlled pitch and yaw angles are to be produced by auxiliary equipment the air flight distance should be large enough to allow a sufficient time interval for its operation. In order to accomplish this, a minimum air flight of 100 ft. was desired. Air flight should not exceed 300 ft. for any launching angle down to 10 degrees in order to obtain good control of the flight path.

Propellants considered for the launcher included rockets, steam, explosives, and compressed air. The use of rockets, steam, or explosives involves complications which are not present with the use of compressed air. The initial capital expenditure would be greater with combustible propellants and a more complex control system would be necessary. In addition, the expense of maintenance and operation of the equipment would be higher. Less hazard exists in the use of compressed air than in the use of alternative propellants. With the Fixed-Angle Launcher, launching velocities of the required magnitude had been achieved at moderate air pressures and with an air receiver of reasonable size. Consequently a compressed air system was chosen for the Variable-Angle Launcher.

A study of curves relating tube length and diameter, projectile weight, tank volume and pressure, and terminal velocities indicated that a 300-ft. launching tube combined with and air receiver capable of holding 500 cu. ft. of air at 1,000 psi would be the most satisfactory of the possible combinations. Accordingly, a length of 300 ft. was required for the structure which would support the launching tubes. While only one launching tube was planned for the initial installation, it was intended that several additional tubes and launching devices would be subsequently installed in the supporting structure. The weight of these additional launching devices was estimated and included in the load to be sustained by the structure. A width of 22 ft. was chosen for the steel bridge structure which would support the tubes. As a result of preliminary design studies a truss depth of 35 ft. was selected in order to minimize tube alignment variation due to differences in the bridge deflections between a 0 and 40 degree position of the launcher bridge. Welded construction was adopted to obtain maximum rigidity with minimum weight.

The selection of a body of water for the location of the launcher required the consideration of depth, variation in water level, and range. Experience with the fixed-angle launcher indicated that water depths between 100 and 150 ft. are required. Depths substantially less than 100 ft. are undesirable because some projectiles would strike the bottom of the reservoir, interfering with the underwater flight of the projectile and damaging it. Water depths in excess of 140 ft. are undesirable because diving recovery operations are difficult. Accordingly, seasonal variation in water level should be limited to about 50 ft. in order that the water depths would be between the limits indicated. Range length of at least 3000 ft., with water depths within the permissible limits, was required.

Several sites were investigated in the south-west and none was found which so completely filled all of the requirements as the area adjacent to the existing facilities at the Morris Dam torpedo station. The presence of existing shop and dock facilities and the nearby location, in Pasadena, of the

Underwater Ordnance Department of the Naval Ordnance Test Station were important factors in favoring the selection of this site. The climate is favorable to the operation of the launching ranges especially from the standpoint of photographic recording of water entry conditions. This site satisfied the requirements for range and depth of water and offered many advantages over other sites considered.

Several schemes for supporting the launcher bridge in its various positions were studied. The one which was adopted was the most economical of the schemes studied and offered additional operating advantages. This plan has the launcher bridge supported at the lower end by two barges (Fig. 4). The upper end of the bridge is supported on a welded structural steel carriage which travels on rails anchored to the 45-degree concrete slab. The launching angle is changed by moving the upper end of the launcher up or down the tracks on the 45-degree slope. The barges move outward from the shore as the bridge is moved to flatter angles. The weight of the launcher bridge and carriage is balanced by a counterweight on the back slope of the peninsula. A change of angle of the launcher bridge is accomplished by means of a motor drive acting on the cable which attaches the bridge support carriage to the counterweight car. In addition to the requirements cited above for this device it was considered desirable to design the bridge so it could be rotated in azimuth so that projectiles which might ricochet at flat angles would strike the side of the hill on the opposite side of the lake.

Following the selection of site and type of structure the final design was commenced. The major components of the facility were

1. The foundation
2. The concrete structure
3. The launcher bridge and supporting connecting bridge and carriage
4. The barges
5. The counterweight car
6. The cable systems and drive machinery.

After the schematic plan of the launcher had been decided upon, a thorough investigation of the foundation area was conducted. Surface inspection of the 45-degree slope for the launcher slab showed the rock to be badly fractured and it was evident that no conclusion of value could be reached regarding the stability and strength of the foundation without extensive exploration. The geological character of the San Gabriel Canyon was fairly well known through the exploration work which preceded the construction of Morris Dam and San Gabriel Dam No. 1, just downstream and upstream, of the project, respectively. Also, an alternative dam site near the project had been explored and other explorations conducted which contributed to the available information. To augment these data a comprehensive exploratory program was undertaken. Four 3-in. diameter diamond core holes of 140 ft. average depth were drilled and showed about 50 percent core recovery. Three test pits, two test trenches and an exploration tunnel completed the exploratory program which will be described in more detail in a Paper No. 2.

On the basis of surface observations and on the results of subsurface explorations it was concluded that the foundation for the launcher slab could be made satisfactory for the proposed structure by proper treatment with consolidation grouting and sufficient stripping of loose surface material.

After first removing 24,000 cu. yd. of loose material from the slopes the fissures were filled with cement grout pumped into diamond drill holes. Over

10,000 barrels of portland cement were used in this stabilization operation at an average rate of 3.4 sacks of cement per foot of drill hole. Core drilling subsequent to the grouting disclosed that the seams were well filled with grout.

The removal of nearly 30 tons of earth and rock, much of which was deposited at the toe of the launcher slope, with the consolidation grouting improved the stability of the foundation to the point where a factor of safety as large as for the other structural components was realized.

The concrete launcher slab, from 4 ft. to 8 ft. in thickness, was designed to resist large uplift forces occasioned by recoil and counter-recoil forces when projectiles are launched. These forces, originating at the launching tube, are transferred downward from the bridge through the carriage to the locking pins in the heavy steel rails anchored to the launcher slab. Accurate shop fabrication and careful positioning of the anchor bolts and rails in the field was necessary.

The counterweight slab, on the other side of the ridge, provided a base for the rails for the counterweight car. The slab, pneumatically placed, receives the load of the 1,200,000 lb. car through its 20 wheels and is 14 in. thick with moderate reinforcement. The foundation, by virtue of the nature of the loading and the flatness of slope required only stripping to grade prior to placing of the slab.

The principal part of the concrete construction consists of the cellular structure over the ridge between the launcher slab and counterweight slab. The rails for the carriage and counterweight car are continued from the respective slabs to the top level of the cellular structure on slabs integral with the side walls and diaphragms. Through careful functional design much use was made of the space within this structure. Horizontal and vertical diaphragms were used as floors and cross-walls of rooms to house electrical and electronic control and recording equipment, operating machinery and other apparatus necessary to the proper functioning of the launcher and the recording of test data. In all there are seven levels, the uppermost carrying the main drive machinery by which the bridge is moved.

The launcher bridge is a movable, all-welded bridge with its 300-ft. span supported on one end by the movable carriage on the launcher slope and on the other end by the connecting bridge and barges. The main trusses of the launcher bridge are 12-panel Pratt type, 22 ft. center to center and have a height of 35 ft. between chord lines. In lieu of the usual X-bracing for the transverse frames a three story, two bay rigid frame was selected to provide horizontal framing for additional decks and corresponding open areas for launching devices.

For the initial installation, a 22 1/2-in. torpedo launching tube was designed and installed in the west bay of the first deck (Fig. 5). Later a 32-in. tube was added. Compressed air for launching is contained in a 500 cu. ft. all-welded air flask located above the breech end of the tube. The flask is designed for a working pressure of 1000 psi resulting in walls of 3-in. thickness. Air is provided to the flask by a 150 HP Y-type 4-stage compressor mounted on a platform of the bridge support carriage. The high-pressure air is released into the tube through a Y-joint by means of a specially designed quick-acting valve. This 22 1/2-in. sleeve valve, built into the central portion of the air flask, operates in one-tenth of a second from the closed position to the full open position.

Access along the bridge is provided by a steel deck grating and by an

adjustable stairway for use when the bridge is at steeper angles. At the breech end of the tube there are additional stairways and platforms for access to the air flask and valve.

Design loads for the bridge included the dead and live loads for the presently installed items as well as for anticipated future installations. Other design loads included wind and seismic loads, lateral impact during launching of a projectile, longitudinal reaction loads and torsion induced by differential displacement of one barge relative to the other. To resist these loads an all-welded structure was designed to minimize dead load and increase vertical rigidity as compared to the alternative of a riveted structure. Increased rigidity without proportional increase in dead load tends to minimize tube alignment variations due to differences in bridge deflections between a 10 and 40 degree position of the launcher bridge. The bridge support carriage is a welded structural steel frame carried on special trucks which roll on the heavy rail sections. There are hydraulically operated locking pins which pass through sleeves in the rails to anchor the carriage during launchings. Since the barge end of the bridge can resist only vertical loads, the horizontal loads are resisted by the carriage. The carriage has a heavy center weldment with a vertical-axis pin to carry horizontal loads from the bridge and has two sections of circular track which support the vertical loads and permit rotation of the bridge in azimuth. A heavy beam provides the attachment for the counterweight cables.

The outer end of the launcher bridge is supported by the connecting bridge, also of all-welded construction (Fig. 6). Weighing approximately 90,000 lb. it has two main trusses of 95-ft. span inclined so that they are 22 ft. apart at the level of the barges and close together at the top where the main bridge connections are placed.

The 68-ton barges are each 35 ft. by 60 ft. by 12 ft. and are of welded steel plate. The ends of the barges are sloped to clear the rock slope when the launcher is in its steepest position. Under normal conditions the barges have a draft of 10 ft. and a freeboard of 2 ft. The interior of each barge is compartmented to prevent the shift of the 335 tons of water ballast in the case of rolling of the barges about either axis.

The launcher bridge is moved by means of the three-drum drive located at the top of the concrete structure. The drive acts on sixteen 2 1/8-in. wire cables which are attached to the bridge support carriage and the counterweight car.

The operation of moving the launcher from one position to another on the launcher slope is initiated by the disconnecting of instrumentation and service cables leading to the bridge and the withdrawal, hydraulically, of the four locking pins. The carriage is then raised or lowered to the desired position, locking pins inserted and connections reestablished.

Torpedoes are prepared for launching in the torpedo shop adjacent to the launcher. Internal instrumentation is installed in this shop before the missile is rolled across to the loading platform next to the launcher slope. A level platform projectile car is brought to the same level as the loading platform and the torpedo and carriage is rolled over onto it. The projectile car is then raised or lowered to the level of the bridge support carriage platform where the projectile is transferred to the carriage deck. A 3-ton overhead crane is used to place the projectile in a projectile loader which is aligned with the tube, whatever its inclination. Firing is accomplished from the supervisory control station where an operator has available all information concerning the

readiness of the launching apparatus and the instrumentation for recording the test data. A complex electronic control system, located in the main concrete structure and in the control station, is required to assure the accurate and proper sequencing of the steps in the launching process.

The recording of the water-entry phase of projectile launchings (Fig. 7) is accomplished by means of general side view cameras, cameras in the side view camera car positioned opposite the entry point and a camera carried by an overhead cable and positioned over the entry point. Underwater trajectory is obtained from the recording, by means of a hydrophone array and recording oscilloscope, of an intermittent sound source on the projectile. Other instrumentation, internal and external, yields information on the position, attitude, velocities, and accelerations of the projectiles from the moment of launching through the water-entry phase.

These test data together with the structural damage studies provide information for the designer which is used to develop stable, structurally sound missiles and ordnance components. This $2,000,000 facility, the only one of its kind in the world, is taking an active part in increasing the effectiveness of the United States Navy.

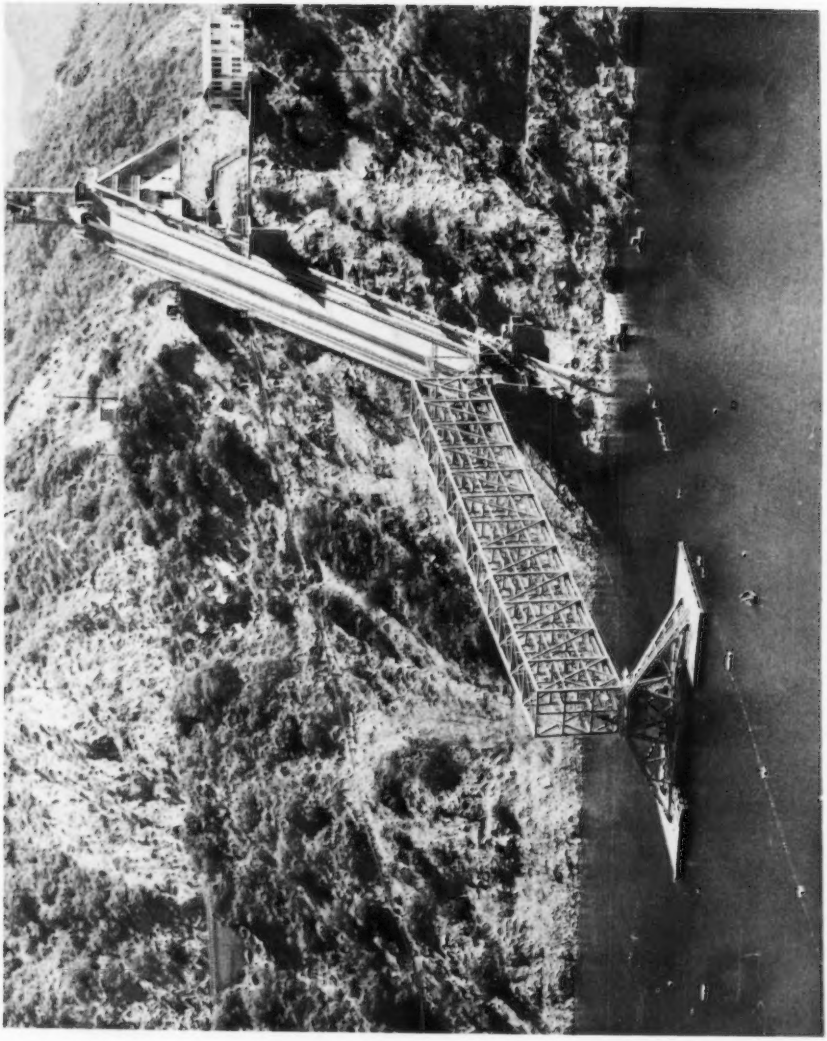

Fig. 1. The Variable-Angle Launcher at Morris Dam Torpedo Range

Fig. 2. Aerial View of Launching Facilities at Morris Dam Torpedo Range

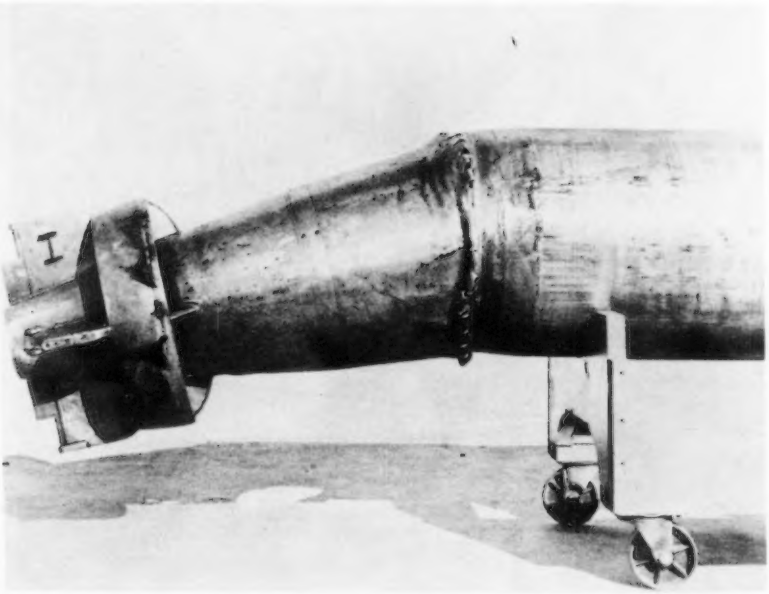

Fig. 3. Structural Failure of a Torpedo Afterbody Caused by Shock Loading at Water Entry.

Fig. 4. The Variable-Angle Launcher and Torpedo Range With Morris Dam Spillway in the Distance

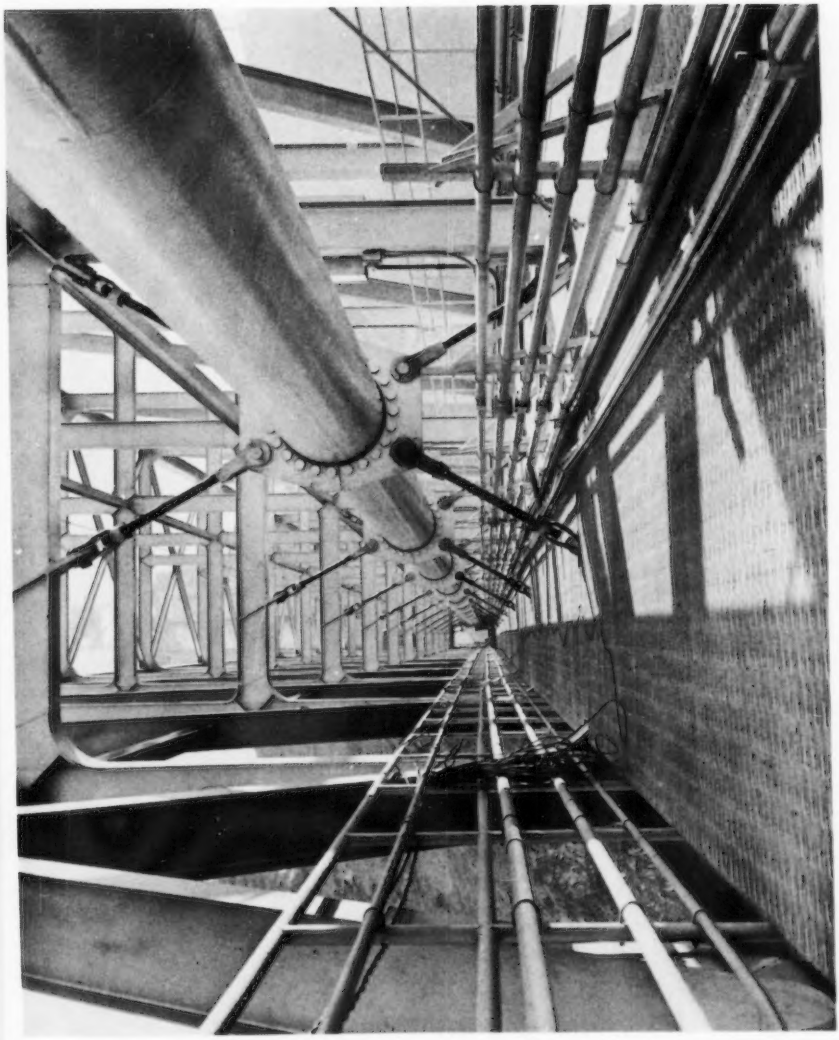

Fig. 5. Torpedo Launching Tube and Deck Installed on the Launcher Bridge

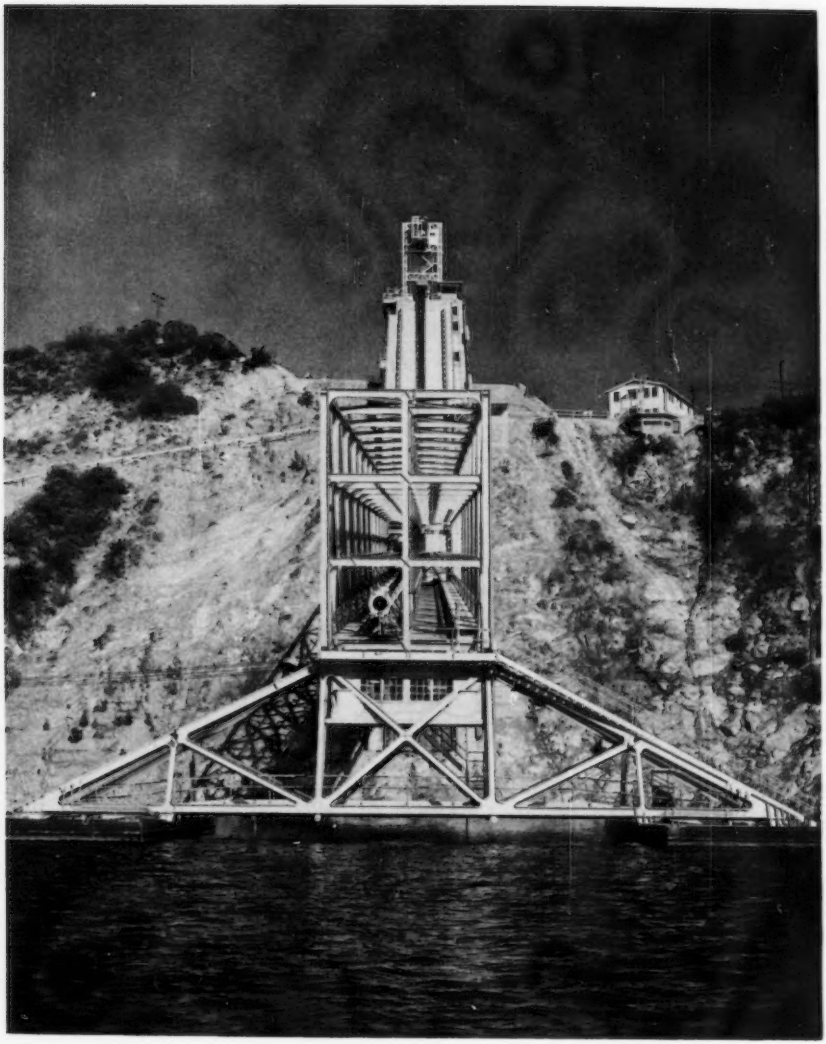

Fig. 6. Connecting Bridge Supporting the Outer End of the Launcher Bridge

Fig. 7. Spray Rises High into the Air from a Torpedo Entering the Water

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VARIABLE-ANGLE LAUNCHER: CONCRETE STRUCTURES AND FOUNDATION TREATMENT

James H. Jennison,* M. ASCE
(Proc. Paper 1340)

FOREWORD

The design and construction of the U. S. Naval Ordnance Test Station's "Variable-Angle Launcher"—a unique $2,000,000 test facility at the Station's Morris Dam Torpedo Range near Azusa, California—is described in Proceedings Paper 1339 through 1343. Designed to launch various types of projectiles into the water under controlled conditions at high velocities and variable entry angles, the variable-angle launcher permits the detailed study of projectile water-entry performance. It has served as a valuable tool in developing improved air-launched torpedoes which can be released by aircraft at high altitudes and at high release speeds.

The launcher consists of a 22 1/2-in. torpedo-launching tube, 300 ft. long, mounted on a movable 300-ft., all-welded, steel bridge. The upper end of the bridge is supported on a welded structural steel carriage which rides on rails up and down the 45° slope of a peninsula jutting into Morris Dam Reservoir. The lower end of the launcher bridge is supported by a second, transverse bridge 95 ft. long, which rests on two steel barges floating in the water. The weight of the launcher and carriage is balanced by a 600-ton counterweight car which rides on rails up and down the back slope of the peninsula. The elevation angle can be varied between 10° and 40° by moving the upper end up or down the tracks on the 45° slope. The launcher can also be rotated in azimuth by adjusting the position of the barges and transverse bridge.

Projectiles are launched at velocities up to 800 ft. per sec. by means of a compressed air system. The compressed air, at 1,000 lb. per sq. in., is contained in a 500-cu.-ft., all-welded, air flask, and is released into the launcher tube by means of a quick-acting 22 1/2-in. sleeve which opens in 0.10 sec. A complex electronic system controls the launching process. Elaborate instrumentation—photographic, acoustic, and electronic—provides information

Note: Discussion open until January 1, 1958. Paper 1340 is part of the copyrighted Journal of the Construction Division of the American Society of Civil Engineers, Vol. 83, No. CO 1, August, 1957.

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on the position, attitude, velocities, and accelerations of projectiles during launching and water entry.

Proceedings Paper 1339 presents the need for a research facility of this sort, outlines the planning of the structure, and describes the functions and characteristics of the structural elements. Proceedings Paper 1340 describes the extensive foundation treatment required and the design of the concrete structures. Proceedings Paper 1341 presents a description of the steel structures, including the 300-ft. span, all-welded, launcher bridge—longest all-welded bridge span in the United States. Proceedings Paper 1342 discusses the mechanical and electrical features of the launcher, including the projectile-launching equipment, handling and transport equipment, operating equipment used to change the launcher angle, and test instrumentation. Proceedings Paper 1343 summarizes the actual construction of the facility, including some unusual solutions to the construction problems.

INTRODUCTION

This article is the second of a series describing a unique ordnance testing facility of the U. S. Naval Ordnance Test Station called the Variable-Angle Launcher. As described in Paper 1339, this device is used in ordnance research to launch missiles into the water at high velocity and at variable trajectory angles. In order to permit variation in trajectory angle, the launcher bridge, a 300-ft.-span all-welded steel-truss structure, is supported at the outer end on two barges connected by a 95-ft.-span bridge and at the shoreward end by a carriage traveling on a 45° ramp. Adjustment of the angle of inclination of the launcher bridge is accomplished by moving the carriage up or down the ramp.

To provide the running surfaces both for the carriage supporting the launcher bridge and for the counterweight car, two ramps, preferably with opposite slopes, were desired. This requirement was fulfilled economically in San Gabriel Canyon, California, by placing the supporting structure over a narrow peninsula which provided natural slopes of approximately 45° on the southerly side and 30° on the northerly side.

The top of the peninsula was benched by removal of the earth overburden to expose satisfactory foundation material. On the benches thus formed, a cellular concrete structure was built to continue the ramp slopes to a small platform near the apex, where the main drive machinery was installed. The cellular spaces within the main structure were used to house the machinery and instruments necessary for operation of the launcher. Balconies provided access to the launcher ramp from the main structure at several points.

The launcher ramp is built on the southerly slope of the peninsula and serves two purposes. First, it provides the 45° surface for the rails on which runs the carriage that supports one end of the launcher bridge. Second, by virtue of its mass and because the concrete is doweled to the foundation rock, it provides resistance to uplift forces imposed by the carriage because of recoil reaction when projectiles are launched.

The counterweight ramp, as the name implies, is used to support the track for the counterweight car. It is built on a 30° slope and primarily is designed to sustain the wheel loads of the counterweight car. The counterweight car is a composite structure consisting of a welded steel chassis keyed to a

reinforced concrete car body. The car body was constructed of a dense concrete containing scrap steel. The attachment of cables to the car by means of a weldment with heavy reinforcing bar anchorage is an interesting feature of the design.

The outer end of the launcher bridge is held in position by wire rope lines passing over blocks at widely separated anchor points on the shore at each side of the launcher. From the anchor points, the lines are brought back to winches at each side of the launcher ramp. The anchorages to which the blocks at the lake shore are attached were designed for large wind-load forces, varying in direction and magnitude to correspond to various positions of the launcher.

The discussion which follows describes the foundation treatment, design criteria, and concrete structures of the Variable-Angle Launcher.

Foundation Investigation and Consolidation Grouting

The foundation problem immediately was recognized as one of the most important aspects of the project. The site was selected because it possessed a number of natural advantages, but it was known from the beginning that the stability of the rock slopes would have to be determined before construction could proceed safely.

A number of earlier exploratory studies of the San Gabriel Canyon had been made in search of satisfactory dam sites. The project is located between two successful dams, Morris Dam, which forms the lake on which the test range is situated, and San Gabriel Dam No. 1, which is a flood-control dam. An earlier attempt to construct a dam farther up the canyon ended in abandonment because of foundation difficulties. A large rock slide occurred about one-half mile upstream from the launcher site on the opposite side of the canyon after the heavy and prolonged rains of March 1938. This slide took place along a plane of foliation in the banded gneiss which dips toward the reservoir in this area. On each side the slide was limited by the faults which were instrumental in causing the slide. Numerous smaller rock slides have occurred along the banks of the reservoir. Consequently, there was ample evidence of the need for a thorough investigation of the foundation material.

The site of the Variable-Angle Launcher is in a region of highly fractured metamorphic and igneous rock and is crossed by numerous fault zones. The mountainous topography is characterized by sharp ridges and deep, v-shaped canyons. The rocks of the region show the results of active weathering.

A study of the local geology of the site of the Variable-Angle Launcher (see Fig. 1) reveals that the southerly slope chosen for the 45° launcher ramp is composed of banded gneiss dipping into the peninsula at an average angle of 40°, i.e., approximately normal to the slope. Rock is exposed in the lower portion of the slope, whereas the upper portion is soil-covered. Several minor faults were found, marked by soft crushed rock and some clay. Larger faults were found at some distance from the proposed structure, but none of the faults is active and their location and dip do not endanger the structure.

The top of the peninsula is composed of weathered granodiorite covered by residual soil. The decomposed rock is soft, and is broken by many fractures. The northerly slope is underlain by fractured granodiorite under a surface layer of soil and fill. At the bottom of the counterweight slope the rock is

exposed and is hard, but fractured. Figure 1 shows the geological structure of the peninsula at the site.

To explore the subsurface conditions at the construction site, diamond-drill holes, open test pits, and tunnels were employed. The four exploratory diamond-drill holes total 558 ft. in length. They were drilled with a bit that produced 3-in. cores. Core recovery of only about 50%, frequent loss of drill water, and failure to develop pressure during hydrostatic tests showed that the rock was extensively fractured. Difficulty was experienced in cementing the holes sufficiently well to allow drilling to proceed. In hole No. 4, which was drilled to a depth of 166.5 ft., the core recovery was almost 100% between depths of 14 and 65 ft.; but even here the rock was fissured, as shown by the fact that drill water escaped from the hole, and that the core was broken into small pieces. Dye was introduced into the water used for pressure tests, and its appearance in the lake indicated that fissures extended to the rock surface under water. Several unsuccessful attempts were made to cement off the fissures, and finally casing was resorted to. The drilling was continued below the 65-ft. depth using a smaller bit that produced a core 2 1/8 in. in diameter. Between depths of 65 and 95 ft. the core recovery was over 60%. Below the 95-ft. depth the core recovery was only 22%, but this low value could be attributed to the incompetence of a new driller employed on this portion of the job. In general, the exploratory core drilling indicated loose, fractured rock near the surface, gradually becoming tighter at great depth although fractured throughout. Drilling and grouting operations later confirmed this evidence.

Test pits were dug with pneumatic spades to expose the conditions prevailing near the surface. These pits revealed the broken and weathered condition of the rock, but gave encouraging indications of its firmness. The granodiorite of the northerly slope and top of the peninsula is fractured badly, and fractures are coated by a film of reddish clay. However, the partially decomposed rock is tight and firm although not hard. The test pits provided much useful information for determining footing depths and excavation limits.

A tunnel 153 ft. in length with a width of 3 ft. and a height of 6 ft. was driven horizontally into the southerly slope, as shown in Fig. 1. This tunnel gave further indication of the fractured nature of the banded gneiss of the launcher slope and revealed fault zones of widths varying from one-half in. to one ft. Since the fault zones dipped into the hill in all cases, they were not considered to be seriously detrimental to the stability of the slope. Only the first 20 ft. of the tunnel near the portal required shoring, indicating the tighter, more stable condition of the subsurface rock of the peninsula.

Having ascertained the subsurface structure of the peninsula, the stability of the slopes and allowable foundation pressures were determined. The most critical and most important area was the 45° slope for the launcher slab and rails. Failure of this slope might occur either as a slide of loose material parallel to the slope and near the surface, or as a deep circular slip. The possibility of a shallow rock slip arises from the fact that the angle of repose of the rock fragments appears to be approximately 45°, which is the slope of the present hillside from the ridge to the bottom of the reservoir. Beneath the water surface of the reservoir, clayey material in the rock crevices has been softened by long submergence. Changes in lake level also tend to reduce stability of the slope by changing both the external and internal pressure loading.

In order to insure stability against a surface rock slip, it was considered necessary to strip the loose rock from the slope and to fill the open crevices in the rock structure with cement grout. The concrete launcher slab also keys the underlying rocks together and prevents their rolling.

The second type of instability is represented by a possible slip along a deep circular arc (see Fig. 1). It was found that changes in radius or location of the assumed circle did not produce much change in calculated stability. Considering uplift from rapid drawdown of the reservoir, but not the effect of earthquake forces, the required slip resistance is equivalent to an average angle of internal resistance of 46°. It is impossible to determine accurately the average shear resistance of the rock mass; but, considering the character of the rock through which the circle passes, and the fact that the planes of foliation dip steeply into the hill and cut across the assumed circle at a large angle, there appears to be little danger of slip along this line. Moreover, the stability was increased appreciably by pressure grouting.

The extreme limit of stability was investigated by making the conservative assumption that the banding of the rock dipping into the hill would not tend to resist the slip, and that the mass was composed entirely of decomposed gneiss similar to the poorest material found in the exploratory tunnel. Thus the advantageous effect of the better materials in the mixture was neglected. If this assumption is made, and the laboratory test data on shear resistance of the poor material are utilized, a limiting factor of safety can be computed which will surely be less than the actual factor of safety. On this basis, a limiting factor of safety of 1.32 was computed for the condition of rapid drawdown of reservoir water. If earthquake forces are assumed to act simultaneously with other forces, including rapid drawdown, the limiting factor of safety is reduced to 1.1. Actually, the real factor of safety of the rock mass on a deep slip plane is much greater than these figures, even before the grouting treatment, because a large proportion of the material was better than the sample selected, and because the structures dip into the hill. By thoroughly grouting the slope, it appeared that the stability of the foundation could be assured with a factor of safety at least as large as that of other elements of the project.

The stability of the counterweight slope also was investigated, but was found to be less critical than that of the launcher slope. As shown in Fig. 1, the material of the launcher slope is banded gneiss, whereas the counterweight slope is composed of granodiorite. The flatter slope of the counterweight side of the hill, the lighter loading, the absence of shock loads and load reversal, and the presence of solid rock at the foot of the counterweight slope all were factors tending to assure the stability of this area.

Material found in the construction zone was entirely adequate for vertical loads. Moreover, the weight of earth removed over the area of the main launcher structure exceeded the load applied by the structure. Conservative values of bearing pressure were selected in order that settlement would be negligible. After removal of the earth and loose rock overburden, the underlying material had an allowable bearing capacity of 6 kips per square foot, except in the region of the counterweight structure where footings were placed on red clay and decomposed granodiorite with an allowable pressure of 4 kips per square foot.

Having determined the character of the foundation material, and recognizing that it would have to be stabilized by removal of loose material and by pressure grouting, the question of continuance at the chosen site was reconsidered. The conclusion reached was that the advantages of the site outweighed the cost of foundation stabilization. No other place in Southern California offered the desired combination of deep water, steep slopes, and accessibility. Another important advantage was the utilization of the existing

facilities which had been developed in connection with the fixed-angle launcher. These advantages are discussed in detail in the first article of this series. Moreover, the study of the foundation problem indicated that, for a cost of less than 10% of the total project, the foundation could be made stable with a factor of safety comparable to that of other elements of the structure. Accordingly, it was decided to undertake the construction work on the site originally chosen.

The first step in the treatment of the foundation consisted of excavating to remove loose material from the slopes and to cut away weathered rock and soil from the top of the peninsula. Thus benches were formed to provide footings in stable, firm material. Approximately 5000 cu. yd. of rock were removed from the launcher slope and deposited at the toe of the slope, and approximately 19,000 cu. yd. of earth and rock were removed from the ridge and counterweight slope and hauled to a dump area. The material removed from the ridge and transported to the disposal area weighed approximately 56,000 kips, compared to the 10,400 kips of superimposed load from the concrete structure, machinery, and equipment. This increased the factor of safety against deep circular slip since the load tending to cause such slip was reduced by 45,600 kips. The material excavated from the launcher slope and deposited at the toe of the slope also added to stability against deep slip failure of the foundation rock.

In order to consolidate further the foundation rock of the launcher, the fissures were filled with cement grout pumped into diamond-drill holes in a zone about 50 ft. wide. This strengthened the foundation and increased its shear resistance to both surface slip and deep slip.

That grouting was necessary, particularly to stabilize the surface material against superficial slippage, was indicated in a number of ways. During excavation of the launcher slope, care had to be exercised to prevent removal of rock below the established grade line. Loss of drill water and difficulty in recovering cores during both exploratory drilling and drilling for the grouting operation also indicated the fractured nature of the rock. Cracks varying from a fraction of an inch in width to almost two ft. in one instance were visible on the surface. Moreover, during grouting, grout occasionally appeared on the surface, and cement consumption was very high until considerable depth was reached. Whether the reduction of cement consumed in the lower stages of the deepest holes indicates deep penetration of grout from the first stages or tighter rock could not be fully established. However, there is every indication that both conditions contributed.

A total of 40,835 sacks of cement was used for grouting the foundation rock, of which 67% was used in the upper 35 ft. of the drill holes. Twelve thousand ft. of grout hole and 400 ft. of core hole were drilled and grouted at an average rate of 3.4 sacks of cement per ft. of hole. The grout was pumped at a pressure of somewhat less than 1 psi per ft. of depth of hole with a maximum of 150 psi used in the deep holes. Excessive pressures were avoided, since it was important to avoid any shifting of rock masses because of uplift pressure.

Further surface stabilization was obtained by removal of loose rock from the slope after grouting and by cleaning the surface hydraulically to insure bonding and keying action with the concrete slab. Additional continuity with the slab was obtained by cementing one inch round reinforcing bars 15 ft. long into the grout holes to provide anchorage for the slab against uplift forces. The slab also was anchored by filling the exploratory tunnel at elevation 1187

with heavily reinforced gunite. Resistance to creep and sliding was obtained by the excavation of six level benches on the launcher slope before placing the concrete slab.

Drilling and grouting operations were highly successful in filling the seams of the rock and tying the mass together. This was determined by core drilling which yielded samples (see Fig. 2) showing seams well-filled with grout. Furthermore, intermediate holes in areas already grouted did not lose drill water and took very little grout. With the several factors discussed above all tending to increase the stability of the foundation, it was felt that ample stability had been achieved.

Design Criteria

The next problem in the design of the concrete structures of the Variable-Angle Launcher was the estimation of loads. Dead loads were computed from preliminary designs. Dynamic loads due to launching were more difficult to determine, but were estimated from strain measurements made on the fixed-angle launcher and from expected recoil forces. Live loads on floors were selected on the basis of the type of occupancy expected. Seismic and wind loads follow conventional practice in the design of buildings and bridges. The loads applied to the concrete structure are indicated in Table I.

Most of the data of Table I are self explanatory. However, a discussion of the wind pressures may be of some interest, although the problem was treated statically in the conventional manner, rather than dynamically. The choice of 75 mph as a maximum wind velocity for design was arbitrary. It is no doubt conservative, since the location in a steep-walled canyon gives protection from any sweeping gale, and protection is particularly good in a lateral direction.

A static design pressure of 30 psf on the projected area is specified for structural members in the AASHO Specifications for Highway Bridges[1] with an allowance of 50% additional for the second truss of the bridge. This is a conservative standard and it appears to agree closely with data compiled by Eshbach.[2]

For a 75-mph wind, the velocity pressure is 14.4 psf. It is customary to multiply this value by a shape factor to obtain an average design pressure applicable to the projected area of a body of particular shape. The only shape factors given for structural members are for wind velocity perpendicular to the web, whereas most of the members of the launcher bridge are placed with the flanges in a vertical plane. However, if it is assumed that these shape factors apply, the design pressure for the structure corresponding to a 75-mph wind is:

$$14.38 \times 2 = 28.2 \text{ psf.}$$

The shape factor of 2 is conservative and is roughly substantiated by two investigators. The pressure was rounded to 30 psf.

The proper allowance for the second truss is difficult to determine.

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1. American Association of State Highway Officials, Standard Specifications for Highway Bridges, 1944, p. 135.
2. Eshbach, Ovid W. Handbook of Engineering Fundamentals, Wiley, 1936, p. 9-65 to 9-69.

Eshbach gives a shape coefficient of 2.7 applied to the area of one truss for a solidity ratio of 0.2, for two trusses separated by a distance of the order of the depth of the truss. The solidity ratio of the launcher bridge is close enough to 0.2 that this shape coefficient is of interest. The shape coefficient of 2.7 for two trusses is equivalent to a 35% increase in projected area of one truss with the applied pressure based on the shape coefficient of 2 for one truss. However, the effect of floor stringers and grating, center verticals, and top and bottom lateral bracing will certainly increase the air drag of the structure. Therefore, the 50% increase in projected area as advocated in the AASHO Specifications for Highway Bridges appears to be justified, and was used.

Shape factors for cylindrical surfaces as a function of length-to-diameter ratio are well established and were used to give the wind loading on the projected area of 10 psf for tubes and 11 psf for the pressure vessel.

Concrete Structures of the Variable-Angle Launcher

The main concrete structure of the Variable-Angle Launcher is a cellular continuation of the slopes of the launcher ramp and the counterweight ramp. It also forms the structural support for the main drive machinery and houses auxiliary electrical machinery and instrumentation. The design was purely functional, with the natural result that the lines are clear and simple. Cantilever balconies, provided for access to various deck levels, enhance the architectural appearance and produce a pleasing effect. Figures 3 and 4 illustrate the modern architectural effect produced by the functional design of the concrete structure.

The walls, floors, and ramps of the main concrete structure act as shear panels and bearing walls to sustain horizontal and vertical force components. Figure 5 shows a cutaway section of the concrete structure. Walls vary in thickness from 12 in. to 24 in. depending upon the loading. Since strength and rigidity were considered to be of primary importance, only a few doors and windows were provided. Access to the work areas on the peninsula was secured through an underpass, and another opening at a higher level gives access through the structure. Since the underpass for the station entrance road (Figs. 1 and 3) was between portions of the structure where the foundation material was considerably different, and where differential settlement might occur, a joint in the walls was made. The slab of the counterweight ramp was made continuous over the joint in the walls, although it was expected that a crack would form because of temperature and shrinkage stress. The longitudinal walls under the launcher ramp were placed directly under the rails of the carriage, and a narrower wall spacing was used under the counterweight ramp to reduce bending stress in the slab. Likewise, heavy transverse walls were provided directly under the main drive machinery to carry heavy vertical loads.

The launcher slope below the main structure was paved with a heavy concrete slab. This slab has a minimum thickness of 4 ft. and was poured directly on the rough surface of the rock foundation. The slab serves the primary purpose of supporting and anchoring the rails for the carriage. However, there is also a track on it for a car to carry projectiles and personnel.

During the launching of a projectile, the large forces listed in Table I are applied to the heavy launcher rails from the 7-in. pins which attach the

carriage to the track. These forces are transmitted through the rails to the foundation slab, which must resist uplift from upward normal components of force and must transmit the shear caused by tangential components of force into the foundation rock. These uplift forces are resisted by the mass of the launcher slab and by the one inch round reinforcing bars grouted into the foundation rock which tie the slab to the foundation. The distribution of force applied to the slab was derived by considering the rails as a beam on an elastic foundation. The result was the usual gradually diminishing pressure (or tension) spreading out from the pin hole where force is applied. The main reinforcement is transverse.

The rails are anchored to the launcher slab by 2-in. bolts on 18-in. centers. Holes in the base plate of the launcher rail for anchor bolts were made 1/4 in. oversize to facilitate alignment of the rails. The anchor bolts were set in the concrete by means of a steel template fitted into the top form used in pouring the slab. A recess, which later was filled with grout, was formed in the concrete under the rails. Shear lugs welded to the base plate of the rails thus were embedded in the grout to transmit both longitudinal and transverse shearing forces. The grout was placed by sealing the space at the edges of the rail base plates with stiff mortar and then pouring fluid grout into the remaining space under the rails through pipe-tapped holes in the base plates.

The counterweight slab is much lighter than the launcher slab, since the counterweight slab merely distributes the wheel loads from the counterweight car to the foundation rock. The slab was made of reinforced gunits with a minimum thickness of 14 in. The plans were prepared to allow use of either reinforced concrete or gunite for the counterweight ramp; gunite was chosen because the bids showed it to be cheaper.

The principal reinforcement of the counterweight ramp is transverse, since the rails offer a reasonable amount of longitudinal distribution of load. The rails chosen for the counterweight track are 90 lb. per yd., and the track was made standard gage.

The counterweight car was designed to suit the special requirements of the launcher. Since it was always to operate on straight track, the standard railroad wheels and axles were mounted in simple pedestal jaws rather than on trucks. The bearings are Timken roller bearings with journal boxes of usual design. Wheel assemblies are spring-mounted to insure uniform load distribution. The car chassis provides for anchorage to the concrete car body and serves as the bottom form for the pouring of concrete. The 16 cables, 2 1/8 in. in diameter, fan out to attach to a weldment at the forward end of the car. To distribute the load from this weldment into the car body, 17 reinforcing bars one inch square were welded to it on each side of the car. Round bars welded at right angles to these one-inch-square bars serve to anchor them and to carry stress due to shear. Figure 6 shows the counterweight car on the ramp before forms or concrete were in place.

The car body was constructed of heavy concrete made by replacing part of the rock aggregate with scrap-steel nuts, bolts, and punchings. The concrete mix was designed to include 3200 lb. of scrap steel per cu. yd., producing a theoretical density of 225 lb. per cu. ft. Three open compartments with stepped bottom and vertical side walls were provided inside the car for the addition of heavy concrete (270 lb. per cu. ft.) ballast blocks or pig-iron ballast as shown in Fig. 5. The possibility that ballast might be placed in one or more compartments without equal distribution throughout the car

necessitated design to withstand considerable bending moment. Since the steel chassis is well anchored to the concrete by means of shear lugs and welded reinforcing bars, the concrete car body and steel chassis were considered to act together as a composite beam. Because of the great rigidity of the car body, it always maintains a straight line, giving linear distribution of load on the springs of the several axles. With this assumption, bending moment for any loading condition can be computed readily.

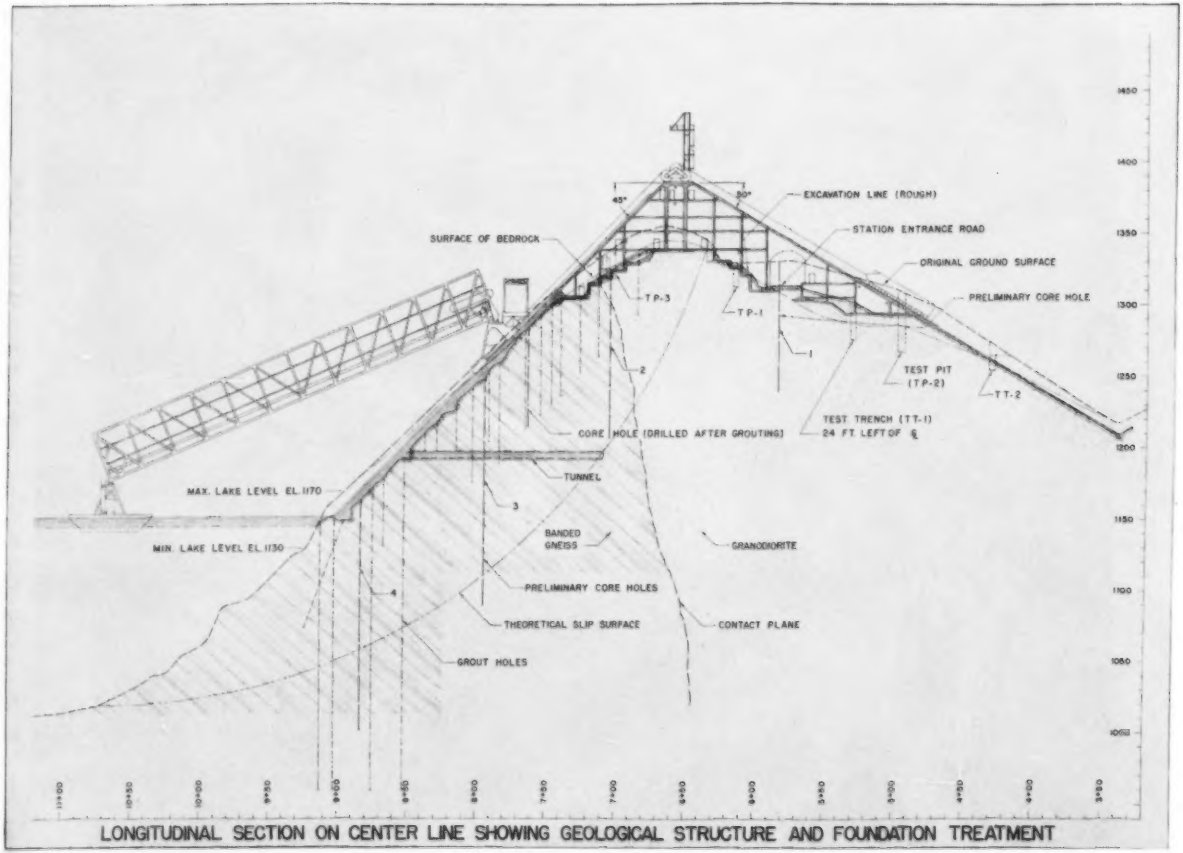
The center of gravity of the fully loaded counterweight car is 6.7 ft. above the rail. The stability of the car during earthquake should prove to be ample, since a static lateral force of 35% of the fully loaded weight would be required to overturn it.

In addition to the major structures already described, a number of smaller concrete structures were required. For instance, to provide supervisory control of launching operations, a small concrete house was built at the edge of the work area where a good view of the range is afforded. Protection of the operator against possible accident or from flying fragments is obtained by using the concrete structure with bullet-proof windows 2 1/8 in. thick.

Beside the launcher ramp and at the same level as the work area, a concrete platform was built to provide access to the projectile car. The deck of the projectile car is level with this platform while loading is being done. The projectile car then is moved to a position beside the carriage for transfer of material to the launcher.

Below these structures, a short distance above high water, concrete platforms were provided on each side of the launcher ramp to support and anchor the windstay winches. One-inch-wire ropes run outward from the two winches to the windstay anchors where large wire-rope blocks are used. The windstay anchors were formed by filling 45 ft. of tunnel 3.5 by 5.5 ft. in cross section with reinforced gunite. The direction of the anchor tunnels coincides with the angle of the windstay lines when the launcher bridge is farthest out. Thus there are components of force toward the slope of the peninsula when the bridge is moved inward. This produces a much less severe condition than would be obtained if there were an outward force component, although some bending will be introduced into the anchorage in either case. As the launcher is moved inward, the design load on the windstays decreases; so the bending and lateral pressure introduced into the windstay anchorages was not a serious problem.

Throughout the design of the Variable-Angle Launcher, an effort was made to secure a maximum of utility through functional design. The result was a group of concrete and steel structures with simple, clean lines. Adequate structural strength and stability was achieved without waste of material, and a pleasing appearance resulted.



LONGITUDINAL SECTION ON CENTER LINE SHOWING GEOLOGICAL STRUCTURE AND FOUNDATION TREATMENT

Fig. 1.

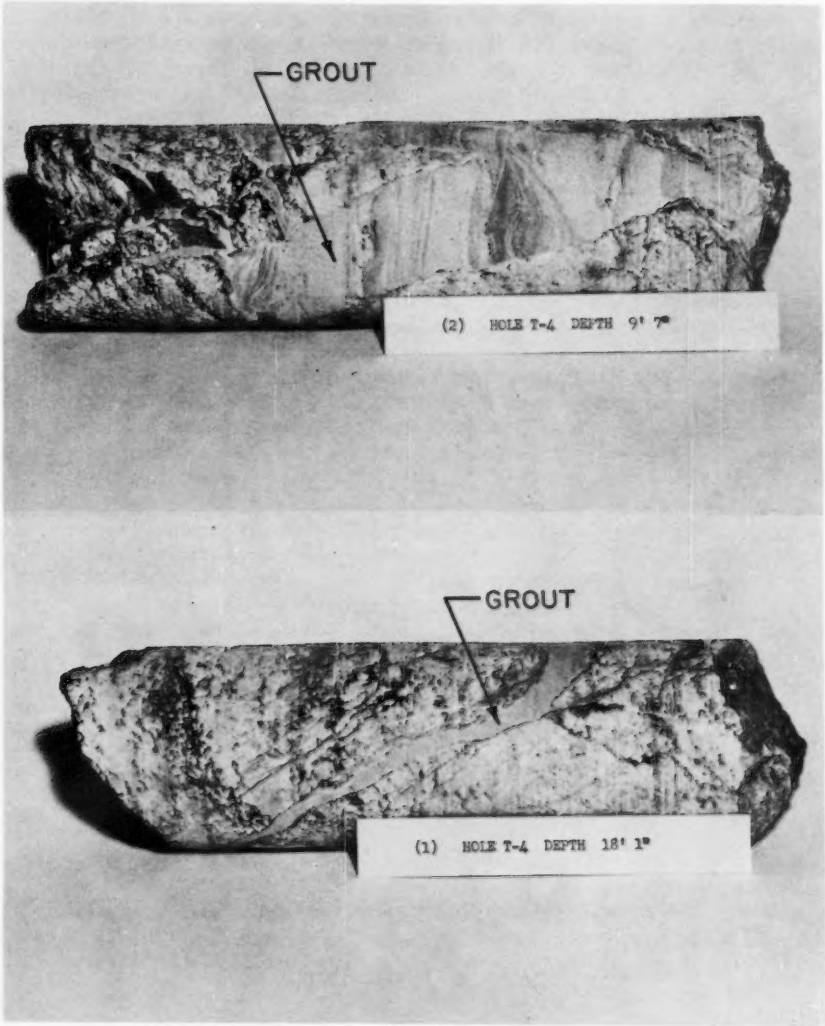


Fig. 2. Core Samples Showing Crevices Filled with Grout. Cores are 2-in. Diameter.

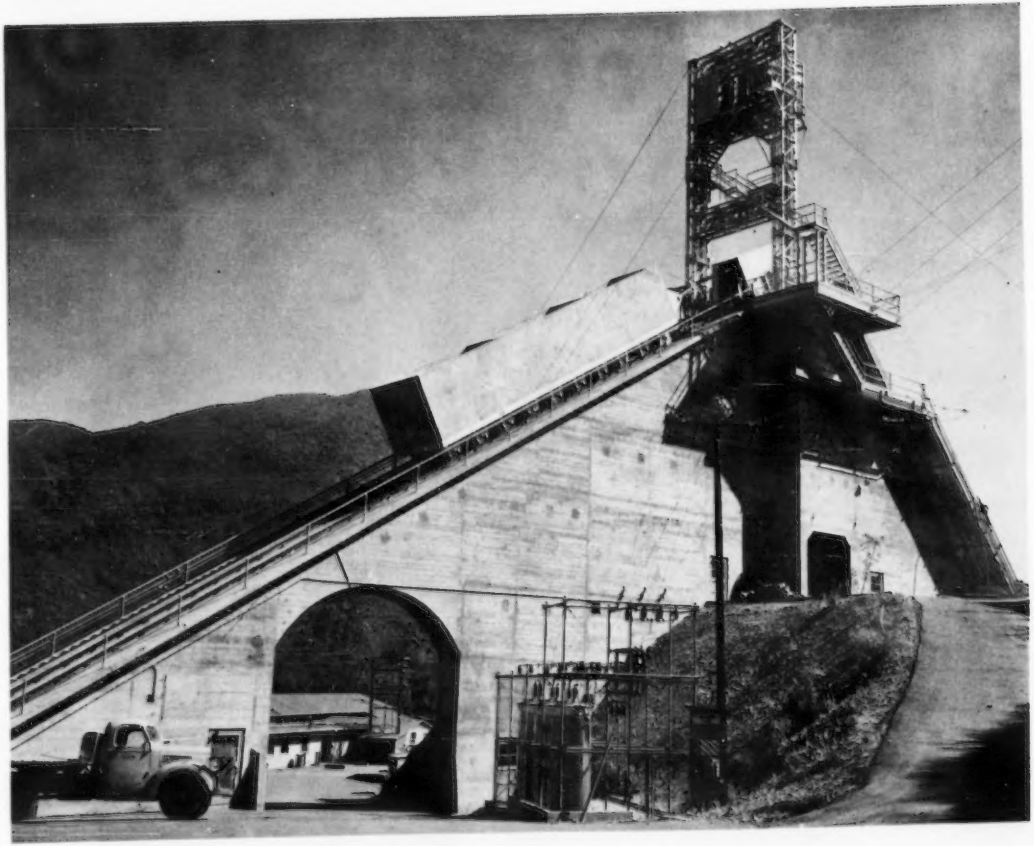


Fig. 3. West Side of Completed Concrete Structure.

Fig. 4. East Side of Completed Concrete Structure.

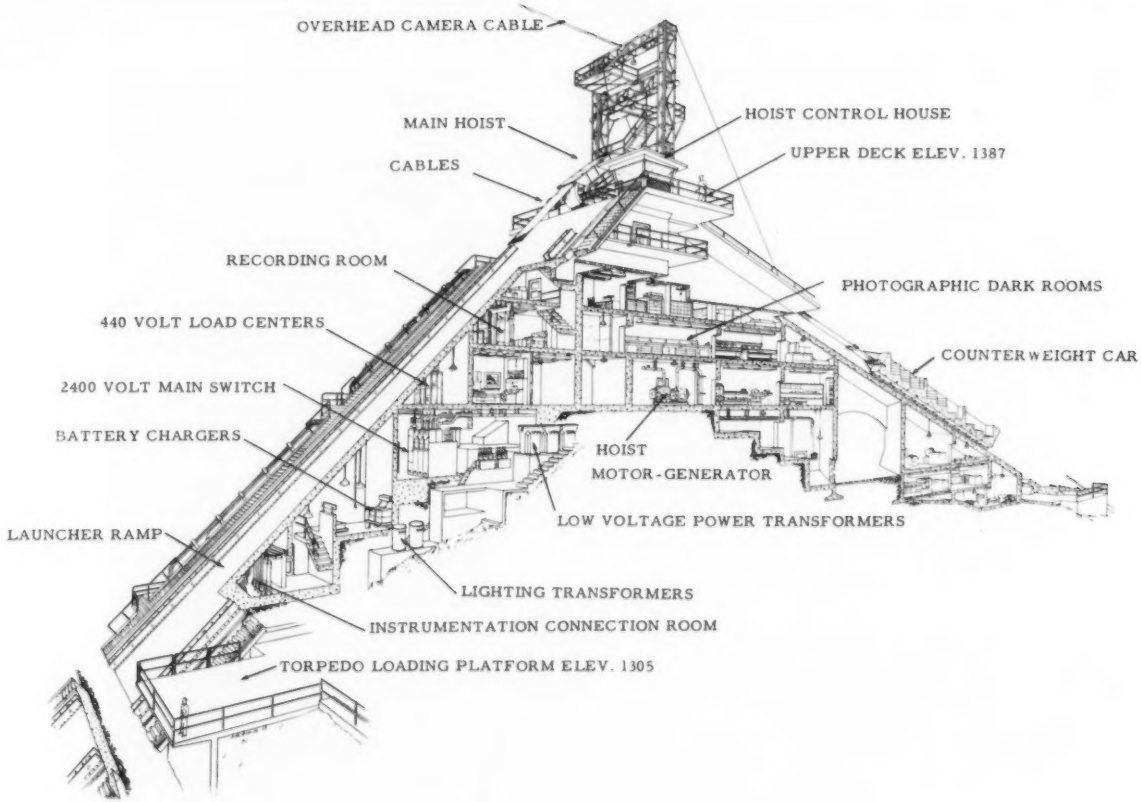


Fig. 5. Cutaway Section of Concrete Structure.

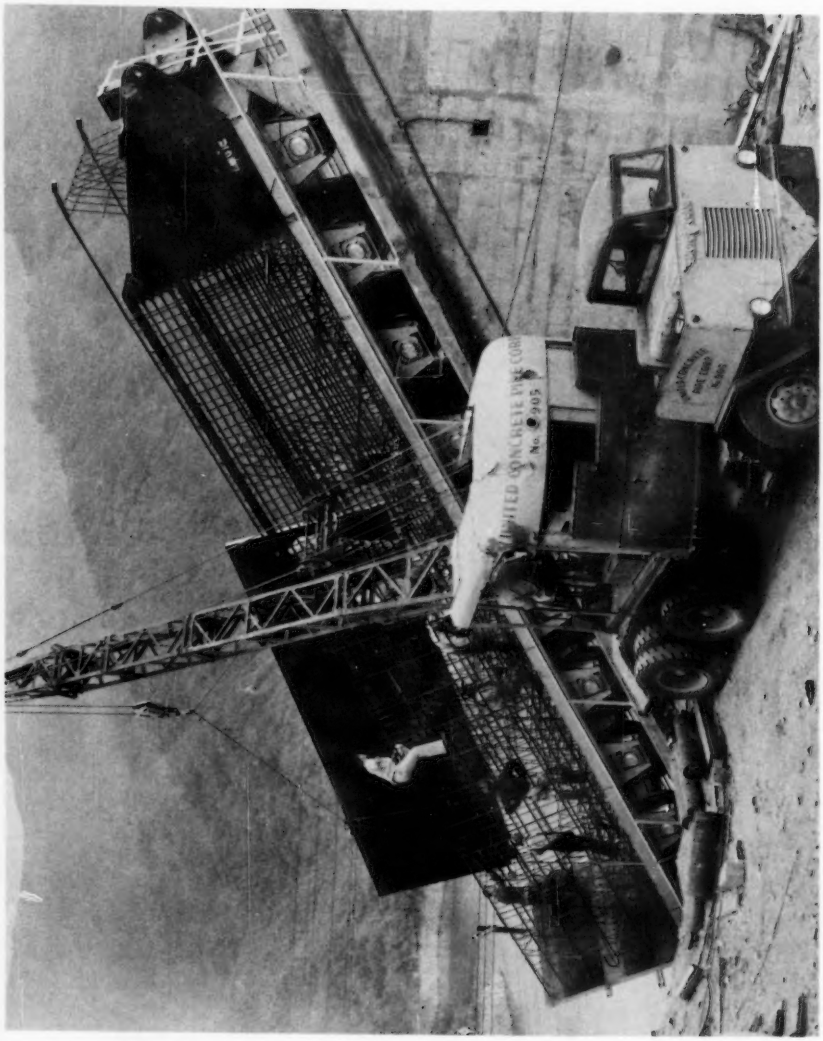


Fig. 6. Counterweight Car on Counterweight Ramp During Construction. Structural Weldment and Reinforcing Steel are in Place and Form Panels for Concrete are being Set.

TABLE I -- LOADS APPLIED TO CONCRETE STRUCTURE OF VARIABLE-ANGLE LAUNCHER

Dead Loads	Kips
Total weight of concrete structure	8660
Downward reaction component of main drive machinery	893
Required total counterweight	1244
Maximum counterweight wheel load (normal to slope)	54
Maximum dead load reaction of launcher bridge (vertical) at carriage	688
Weight of carriage and its equipment	240
Maximum normal wheel load of carriage	61
Dynamic Loads (Due to launching)	**Kips**
Maximum pin reaction component along slope of launcher rail applied by one upper pin	86
Maximum uplift component of one pin reaction (normal to slope)	544
Maximum downward component of one pin reaction (normal to slope)	766
Maximum transverse reaction applied to one rail	280
Live Load	**Units indicated**
Floors	150 psf
Balconies	75 psf
Seismic Load (applied to dead loads including all equipment installations)	10% gravity
Maximum tension on windstay anchorages, for wind velocity of 75 mph (Due to wind load on launcher bridge, connecting bridge, barges, and equipment)	150 kips

Conventional working stresses of 1000 psi for concrete and 18,000 psi for reinforcing steel were used.

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VARIABLE-ANGLE LAUNCHER: STEEL CONSTRUCTION

N. D. Whitman, Jr., M. ASCE[1]
(Proc. Paper 1341)

FOREWORD

The design and construction of the U. S. Naval Ordnance Test Station's "Variable-Angle Launcher"—a unique $2,000,000 test facility at the Station's Morris Dam Torpedo Range near Azusa, California—is described in Proceedings Papers 1339 through 1343. Designed to launch various types of projectiles into the water under controlled conditions at high velocities and variable entry angles, the variable-angle launcher permits the detailed study of projectile water-entry performance. It has served as a valuable tool in developing improved air-launched torpedoes which can be released by aircraft at high altitudes and at high release speeds.

The launcher consists of a 22 1/2-in. torpedo-launching tube, 300 ft. long, mounted on a movable 300-ft., all-welded, steel bridge. The upper end of the bridge is supported on a welded structural steel carriage which rides on rails up and down the 45° slope of a peninsula jutting into Morris Dam Reservoir. The lower end of the launcher bridge is supported by a second, transverse bridge 95 ft. long, which rests on two steel barges floating in the water. The weight of the launcher and carriage is balanced by a 600-ton counterweight car which rides on rails up and down the back slope of the peninsula. The elevation angle can be varied between 10° and 40° by moving the upper end up or down the tracks on the 45° slope. The launcher can also be rotated in azimuth by adjusting the position of the barges and transverse bridge.

Projectiles are launched at velocities up to 800 ft. per sec. by means of a compressed air system. The compressed air, at 1,000 lb. per sq. in., is contained in a 500-cu.-ft., all-welded, air flask, and is released into the launcher tube by means of a quick-acting 22 1/2-in. sleeve which opens in 0.10 sec. A complex electronic system controls the launching process. Elaborate instrumentation—photographic, acoustic, and electronic—provides information on the position, attitude, velocities, and accelerations of projectiles during launching and water entry.

Proceedings Paper 1339 presents the need for a research facility of this

Note: Discussion open until January 1, 1958. Paper 1341 is part of the copyrighted Journal of the Construction Division of the American Society of Civil Engineers, Vol. 83, No. CO 1, August, 1957.

1. Cons. Engr., Pasadena, Calif.

sort, outlines the planning of the structure, and describes the functions and characteristics of the structural elements. Proceedings Paper 1340 describes the extensive foundation treatment required and the design of the concrete structures. Proceedings Paper 1341 presents a description of the steel structures, including the 300-ft. span, all-welded, launcher bridge—longest all-welded bridge span in the United States. Proceedings Paper 1342 discusses the mechanical and electrical features of the launcher, including the projectile-launching equipment, handling and transport equipment, operating equipment used to change the launcher angle, and test instrumentation. Proceedings Paper 1343 summarizes the actual construction of the facility, including some unusual solutions to the construction problems.

INTRODUCTION

This paper describes the design and construction of the major steel elements of the Variable-Angle Launcher Project at the Morris Dam Torpedo Range, San Gabriel Canyon, California. These elements are the main bridge, the connecting bridge, the supporting barges, and the bridge support carriage. Both bridges are all-welded and represent a significant step forward in the application of welding to large structures. Other papers[2] have described the general project and shown steel elements in relation to the entire facility.

Selection of Type of Fabrication

One of the major problems in designing the Launcher was to decide whether the steel structure should be fabricated by welding or riveting. Preliminary studies showed that a welded structure would require appreciably less connecting material at the joints, and that primary tension members would have much smaller cross-sectional areas. The resulting decrease in dead weight would produce lower dead load stresses; thus, compounding the saving. A welded structure being considerably lighter than a riveted structure would therefore show smaller differential dead load deflections with varying angles of inclination of the bridge. Furthermore, welded joints provide full continuity and add to the joint rigidity which in turn stiffens the entire structure. These factors were given careful consideration in selecting the type of fabrication to be used, since it was important that the deflections from all causes be kept small to permit accurate alignment of the launching devices. Misalignment which would be introduced by structural deflections would create undesirable dynamic loads in the system and thereby decrease the value of test data. Welded construction also provides a cleaner structure with fewer sharp corners and greater freedom for attaching testing devices. The maintenance costs are reduced by the elimination of reentrant angles and overlapping surfaces. Riveting, on the other hand, has the advantages of standardization of design and fabrication, resulting in lower unit cost and greater ease of inspection and testing during construction.

During the planning and design of the structure, it was difficult to determine the absolute difference in cost between the two systems of fabrication.

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2. Papers Nos. (1), (2), (4), (5) describe other features of this project.

However, it was decided that an additional cost of 5% to 10% for welding was justified, because of the advantages that would be obtained from this method of construction. Subsequent figures on cost indicated that the welded construction was actually less expensive. The smaller dead load effected savings in the construction of the supporting carriage and barge bridge as well as in the mechanical equipment for moving the bridge. The lower cost was effected even though the design incorporated faired flanges, variable webs, and other details essential to proper welded design which were not common shop practice.

The unusual requirements of this structure probably made it more suitable for welded construction than more conventional projects. The nature of the test work was such that accidental overloads were very probable hence the ultimate strength of the structure was of abnormal importance. The full continuity and high redundancy of this structure provides high ultimate strength, since numerous structural systems are brought into action by plastic distribution under conditions of unusually high load.

Design Criteria

In the design of the steel structure, the controlling specification was based on the 1944 edition of the American Association of State Highway Officials; however, certain exceptions were made in limiting stability factors, for example, secondary compression members were permitted to have a maximum l/r ratio of 200 (instead of 140) and tension members were allowed to have a l/r ratio of 300 (instead of 200 or 240).

The welding was initially designed to conform to the specification of the American Welding Society, 1941 Edition; but final details were checked for conformity with the 1947 Edition. The main change in the specification was to allow the same stress in a full butt weld as in the parent metal. This results in considerable economy in material and labor on main member splices.

The design loading was segregated into basic dead load, which included all fixed structural weight; fixed live load, which included the launching devices, walkways and stairs, and the nominal uniform live load on the various floor systems; moving live loads, which included the recoil, impact, and reaction forces from the projectile; and special loads which included wind, earthquake, uneven support because of a damaged barge, and wave loads acting on the barges. Local high-intensity loads were treated independently for the particular members involved. The design loading conditions are given in Table I.

Barges

The support for the lower end of the main bridge was composed of two barges rather than a single unit in order to minimize the reflection of underwater shock waves caused by the projectile at water entry. The barges, Fig. 1, were of unusual proportions, 35' x 60' x 12', to permit them to move in close to the shore when the bridge is at a maximum vertical angle of 40°. A depth of 12 ft. was required for buoyancy and ballast. The structural frame and shell were designed to withstand stresses introduced by deflections accompanying the flooding of any two compartments of either barge.

Motion of the barges was undesirable during the launching of test projectiles; hence it was necessary to minimize the dynamic motion of the barges.

In order to obtain the desired stability, the barges were deepened and the confined water ballast was enlarged—which increased the inertia and damping effect. The addition of extra bulkheads aided in solving the problem and also reduced the effect from flooded compartments.

The barges were designed for maximum dead load, plus fixed live load, plus recoil; however the moving live load from the main bridge was not included because of the inertia and elasticity of the connecting structures. The dead load of one barge was approximately 136 kips without water ballast; the ballast may be varied, with a maximum of 670 kips. The maximum reaction from the connecting bridge on the barge with unbalanced conditions was 360 kips. Normal live loads on the deck of the barge were considered as well as dynamic water loads (waves) acting upon the barges. Observations of conditions on the lake, together with empirical formulas for wave height, indicated that the barges should be designed to withstand waves of one foot amplitude (two feet from trough to crest). The normal freeboard of the barges was two feet.

Through careful analysis and design of the barges with respect to stability, units were obtained which had large righting moments with small angles of displacement. It is evident from Fig. 2 that the restoring moment increases much more rapidly than the overturning moment, and hence the barges provide a very stable support for the end of the main launcher bridge. The dynamic characteristics of the barges were also studied. It was found that when the two barges were oscillating together, there was no unstable condition but that when the oscillations were opposed with the connecting bridge acting as an elastic torque arm, a critical resonant condition did occur. The problem was solved by modifying the connecting bridge, as shown later.

The stress analysis of the barge structure followed conventional practice. The hull and bulkheads were designed for full unbalanced water pressure. The longitudinal moments and shears were carried by the corresponding bulkheads. Transverse loads were carried by continuous frames between bulkheads. The deck plating was increased to one-half inch material in the vicinity of the connecting bridge. Heel reactions and additional stiffeners were added to the bulkheads receiving these concentrated reactions.

The welded construction of the barges was conventional, following procedures and techniques developed in the shipyards during the war. Automatic welding was used wherever possible, and the welding sequence was analysed and prescribed on the plans so that residual stresses and distortion were minimized. One main transverse joint was required so that the barge could be transported to the site in two sections. This field joint was studied carefully and it was finally decided that a joint without offsets would be satisfactory. Backstepping of this field joint was specified in order to reduce distortion and warping.

Exterior plating and bulkheads were stiffened with angles and tees which were mounted with the parallel leg outstanding. These were line-welded to the plate. The economy of welding was manifested here since "Z" sections or doubled angles would have been required if riveting had been used. Plate tilt brackets were welded at intervals to stabilize the outstanding portion of the angle.

Connecting Bridge

The connecting bridge has a span of 95 ft. with each heel resting at the center of its supporting barge. The two main trusses are tilted to bring the upper chords together. The maximum width of the bridge is 20 ft., the height is 21 ft., and the weight of the structural steel is approximately 80 kips. The edges of the barges are connected to the first panel points of the trusses. These connections are active only when barge motion or non-uniform distribution of ballast occurs.

This bridge receives the reactions from the main launcher bridge and transmits them to the barges. The windstay cables which hold the system at any desired angle of azimuth pass through sheaves which are mounted on the bridge. The bridge was designed with proper torsional rigidity so that it damps out resonant counter roll between the two barges. The walkways on the bridge provide access between the barges and the main launcher bridge.

The primary loads on the connecting bridge are the launcher bridge reaction of approximately 600 kips (both trusses) and its own dead load of 80 kips. Secondary loads such as live loads on the walkways, wind load, and torsional loads from the barges were all considered in the design. Special loads due to damage and settlement of one barge with resultant unequal reactions from the main bridge, were also investigated.

The trusses were first analyzed as planar systems with correction for the angle of tilt under the various load combinations. Then the entire structure was investigated as a space frame to determine the stresses in the bracing systems. These results were incorporated in a torsional analysis to determine stresses and rigidity. An analysis was then made of the dynamic action of the barges in counter roll with the connecting bridge acting as a torsionally flexible shaft. This showed that a danger zone existed as illustrated in Fig. 3. The analysis indicated, however, that non-resonant conditions were not dangerous because of small energy input. Since there is an assured lower limit of wave frequency on the lake, the danger zone disappears if the natural frequency is reduced well below the limit, indicated by Point A in Fig. 3. In the other direction, the curve shows that the power dissipated by one-half the bridge increases as the frequency increases and exceeds the energy input at Point B. Hence for frequencies above Point B there is not enough available energy to excite the system and build up undue motions and stresses. The original design of the bridge has a frequency within the danger zone. Consequently, a redesign was made with heavier members to increase the torsional rigidity and obtain a natural frequency above Point B.

The final trusses were checked for secondary stresses since the rigidity introduced by welded construction was a possible source of high secondary stress. For this analysis, the effective length of a member was taken as the average between the working point length and the length of the uniform cross-section. This was considered conservative since it results in higher secondary stresses than using the full length, and it is not an unreasonable assumption since there will be some deflection in the joint knuckle. The analysis showed that the secondary stresses were relatively low and in no case exceeded the allowable increase in stress permitted by the specifications.

The structural steel fabrication was detailed using faired or "streamlined" connections as shown in Fig. 4. Flanges were stripped from the webs at the ends of the members, and curved plates were welded in to provide flange continuity, Fig. 5. Fitted plates were welded in to provide continuity

for the webs. In general, all curved flanges were stabilized at the midpoint of the curve by auxiliary plates placed normal to the flange and the web, and welded to both elements. On members having a long shear weld on the web, the web was cut out to provide more uniform stress transfer.

In designing all welded connections, every effort was made (within reasonable economic limits) to provide a smooth path for stress flow or transfer, and to avoid angles and other configurations which invite stress concentration, since this in turn, leads to local failure followed by progressive failure to the ultimate. An example of the use of a smooth path for stress flow is shown in the design of the upper lateral bracing system on the connecting bridge. The original design used tee sections and faired end connections and the final design eliminated the many-piece fabrication and substituted a stiffened plate which was better and cheaper.

The main pillow blocks which receive the launcher-bridge end pins are large castings resting on heavy weldments on the top chord of the connecting bridge. These castings are bolted to the weldments, but are insulated therefrom by 5/8-in. sheets of Pabrica to minimize the sound transfer to the water.

Launcher Bridge

The launcher bridge, Fig. 7, is a movable bridge with a 300-ft. span. Both end supports are movable so that the vertical and horizontal attitude of the bridge is variable as well as its absolute elevation which changes with fluctuations in the lake level. The main trusses are 12-panel Pratt type, 22 ft. from center to center, with a height of 35 ft. between chord center lines. The transverse frames at each panel are three-story, two-bay rigid frames providing clear access longitudinally for launching devices. Conventional X-bracing is used in the horizontal planes of the upper and lower chords. The centerline vertical members, as well as the web members of the trusses, were stabilized at the third points by longitudinal stringers. The net weight of the primary structural steel is approximately 400 kips, and an additional 100 kips of secondary structural members. At the ends of the trusses, heavy pin plates and pins were used to provide flexible connection to the pillow blocks on the connecting bridge and to the bearing shoes on the carriage. A vertical pin connection at the carriage transfers horizontal forces from the bridge to the carriage and also permits horizontal rotation of the bridge. The end panels of the bridge were subject to large moments by the pin connections because of the variation in vertical angle, and therefore, required secondary bracing.

The primary function of the bridge is to support the various tubes and devices for launching test missiles. These launching units must be held very close to a true line, since sags or curves will not only upset the test work but also introduce unnecessarily high impact or inertia loads. The low dead load and the high rigidity characteristics of this structure minimized the required adjustment of the launching devices and increased the time available for testing. In addition to the launching units, the bridge supports pressure tanks, valves, fittings, and mechanical equipment for the operation of the tests, and also a self-levelling stairway and platforms for access to the testing equipment.

The loads on the bridge were determined carefully, and the final design was based on the actual dead load of the structural system. The fixed live

load was computed assuming the design load on platforms and walkways to be in place together with all weights of tanks, valves, etc. The uniform load on the walkways was 25 psf, and on the stairway and operating platforms, 50 psf. The combined dead load plus fixed live load gave total loads on the upper panel point varying from 12,300 lb. near the center to 41,000 lb. maximum near the carriage end; corresponding loads on the lower panel point were 28,600 lb. and 70,600 lb. The impact force was assumed to be a moving load of 66,000 lb. The magnitude was based upon experience with previous launchers. The impact was taken as a single load since multiple firing is not contemplated. Since this is an inertia force, the design provided for the action of this force in any direction in a plane normal to the axis of the launcher. Heavy reaction loads parallel to the axis of the bridge were considered in both directions. The recoil force (630 kips) acting above the support axis created sufficient moment in the bridge to require analysis of combined stresses. Wind loads at 30 psf on one and one-half times the projected area exceeded the seismic loads and therefore were used in the analysis of the horizontal bracing. Considering the bridge as a space frame, the loads acting in torsion were determined by an analysis of the torsional rigidity of the preliminary design of the bridge. This was necessary to establish the action of the bridge when one pin end support settled relative to the other following damage to one of the two supporting barges. It was found that an angular rotation of 0.39° applied a torque of 1.17×10^{6} ft. lb. to the bridge, inducing unit stresses within the allowable limits. This torsional moment was equal to and opposed by the moment from the barges.

The initial step in the stress analysis was the establishment of thirteen basic loading conditions and twelve combined loading conditions which were analyzed to determine maximum stress conditions. The truss and bracing was analyzed initially as a pin-connected system for vertical and lateral loads. Then, using a Williot displacement diagram, secondary moments were introduced and balanced by moment distribution. The truss is a relatively light one because of the large height-length ratio which was used to obtain rigidity. Therefore, the problems involved are not typical of general bridge construction. However, in this bridge the secondary stresses, in combination with the primary stresses, did not appreciably exceed the allowable increase of 3000 psi for compression members and 4000 psi for tension members. For analysis, the effective length of the members as described previously was used although the deflections were based upon the pin-connected lengths. This procedure reflected the effect of the rigid welded joints and increased the moments in the members, yet no serious problems due to secondary stresses were encountered. The transverse frames, which were introduced primarily for utility reasons, were found to provide strength coupled with torsional flexibility a desirable feature in this particular structure. These frames were analyzed for the various loading conditions and corrected for unbalanced shears. The member sections were selected by using moment curves and taking the net moment at the end of the faired connection. Loads from various analyses were combined. For example, the exterior vertical legs of the rigid frames have to withstand bending moments due to the transverse frame action as well as the primary axial direct stress and secondary bending moments since the frame legs are also vertical web members of the main truss. The torsional analysis of the bridge required that it be treated as a pin-connected space frame, and therefore the rigid transverse frames could not be handled as such. Since, in the space frame, the only attachments to the transverse

bents are made at the corners, an equivalent diagonal was determined which would let the frame deflect the same amount under diagonal loads as would the rigid frame system. This member was then substituted and the analysis completed. It is of interest that this equivalent diagonal was greatly overstressed, but the introduction of an actual member in place of the frame would have necessitated a much heavier section thus increasing the torsional rigidity and, correspondingly, the stresses in other members. For verification, an approximate scale model was constructed of brass, and a torsional analysis made of the model. Physical torsional tests of the model gave results almost identical to the analysis and confirmed its validity.

It was found that small longitudinal stabilizing members which were primarily for utility requirements proved to be valuable in reducing the minimum size of main members which are governed frequently by l/r requirements even on tension members. The action of these members in maintaining the frames in a planar condition was also important.

The heavy pin-connections at both ends of the bridge are subject to complex and variable axial and bending loads. The required strength with a minimum of weight and material was obtained by using variable-section built-up members. In such details the welded fabrication is clearly superior in efficiency and economy.

The typical joint details were similar to those described for the connecting bridge. Placing the flanges of all truss members in the same plane permitted excellent streamlining of the joints with respect to the major stresses. All stabilizing or stiffening plates introduced into reentrant angles normal to the axis of the angle were snipped to break the welding around the corner and eliminate possible stress concentration at that point. The radii used in streamlined fittings were never less than 3 in. and usually about 6 in. In some cases, the radii were increased to extend the haunch effect and avoid excessive size throughout a long member. One such case was the outside vertical leg of a transverse frame where a smaller fillet at the lower connection would require a heavier member for the full height of 35 ft. (unless an expensive reducing splice were introduced). All major welds were butt welds with double bevels on both members to obtain good penetration and fusion. The use of 14-in. members on the truss permitted a wide range of weight and strength while retaining simple details of alignment and connection (Fig. 6).

The main reaction girders are welded, tapered sections designed to sustain the applied loads without introducing useless dead weight. The initial pressure-tank installation (approximately 90,000 lb. dead load) introduced eccentric lateral loads on horizontal members of the transverse frames when in the inclined position. Therefore, special connections and local strengthening of the supporting beams were required.

A movable stair, so constructed that the treads are always level, was provided along the lowest level of the main bridge and is automatically positioned by a linkage to the connecting bridge.

Carriage

The carriage is a pyramidal structure resting on trucks which ride the 45° launcher ramp. It provides a horizontal platform to support one end of the main launcher bridge. The platform has a heavy center weldment which receives the vertical axis pivot of the main bridge. Through this pivot all

horizontal load components are transmitted. At the outer edges of the platform, two sections of curved track support the vertical loads which are transmitted from the bridge to the carriage by sliding shoes. A heavy beam provides for attachment of the sixteen cables from the counterweight car. The wheel assemblies not only have main wheel journals, but also are fitted with hydraulically operated locking pins which pass through sleeves in the main track when the launcher is positioned for test work. A small overhead crane rides on the carriage and facilitates handling of the projectiles.

The carriage unit is designed so that it can be anchored at many positions from bottom to top of the ramp. It thus provides a movable support and anchorage for the shore end of the launcher bridge. Since the other end of the bridge is supported on the barges which can only resist vertical loads, all horizontal loads and horizontal components of inclined loads must be sustained by the carriage with assistance in certain cases from the windstay cables.

The dead load of the carriage structure is 136 kips. Other loads applied to the carriage are listed in Table I.

The general framing of the carriage has been shown in preceding papers. Rigid frame bents were used on the axis of each track with diagonal transverse bracing. The two basic loading conditions were: (1) Dead loads only applied to an unlocked carriage (during change of position); and (2) full dead, live, and dynamic loads applied when the carriage was locked to the track (during test work). Both conditions were investigated for several positions of the main launcher bridge with variations in vertical and horizontal angles. Large dynamic loads due to test work were applied at a vertical angle of 45° to axis of the track or nearly parallel to it, and simultaneously at a variable horizontal angle of as much as $22\ 1/2^{\circ}$. Thus many systems of loading could be imposed upon the structure and adequate strength had to be provided for all cases.

The revolving platform was another space structure. Movable loads introduced by the projectile handling carts were supported on curved beams concentric with the main pivot. The fixed platform and overhead crane were conventional design problems.

The details of design for welded construction introduced some complex problems. For example, closed or nearly closed sections in the main deck grillage made welding accessibility poor and so required careful study of assembly sequence. The problem of warping and twisting was also investigated since it was necessary that the curved track for the main bridge shoes be level. Although every effort was made to minimize distortion, it was finally concluded that a low melting point alloy filler would be required to provide an adequate base for the track. The main cable attachment beam was a very heavy weldment requiring multiple pass welds with heavy beads. Symmetrical welding was recommended and proved to be satisfactory. Reentrant angles along stress lines were avoided wherever possible, and heavy welding fillets were introduced to avoid sharp angles.

Discussion

The design described above has resulted in a very clean and efficient structure (Fig. 7). All work has been checked, and there is ample strength with a minimum of dead load. A review of the design plans shows that almost

all material throughout the structure (excluding equipment, of course) is actively resisting applied loads. Not all material is loaded to full capacity, but there is a minimum of idle material beyond points of stress transfer. Furthermore, there is no appreciable amount of material working at reduced stresses due to limitations imposed by reduced sections at connections. The general appearance of the structure is excellent, bearing out the old adage that "good design always looks right."

An auxiliary investigation showed that the welded design saved between 35% and 40% of the dead load weight that would have been required for a comparable riveted design. In this respect, it may be felt that excessive strength is provided by welded construction, but another auxiliary investigation of load factors (rather than safety factors) showed that the ultimate strength of the structure was not excessive and, in view of the use of the structure, was only nominal.

A valuable feature which resulted from the welded design was the simplicity of making changes in details and/or strength. From the nature of the work, more than the usual number of changes were introduced during design, and these necessary changes were made easily.

On the basis of this structural design problem, it was concluded that welding can be used without additional cost (actually at a saving in this case) and that the resulting structure is superior in all respects to a riveted structure. This project has shown that welded construction is efficient and economical if the decision to weld is made initially, and then all design and detailing is planned accordingly. Mixed or "crossbreed" designs will prove to be expensive in any type of construction.

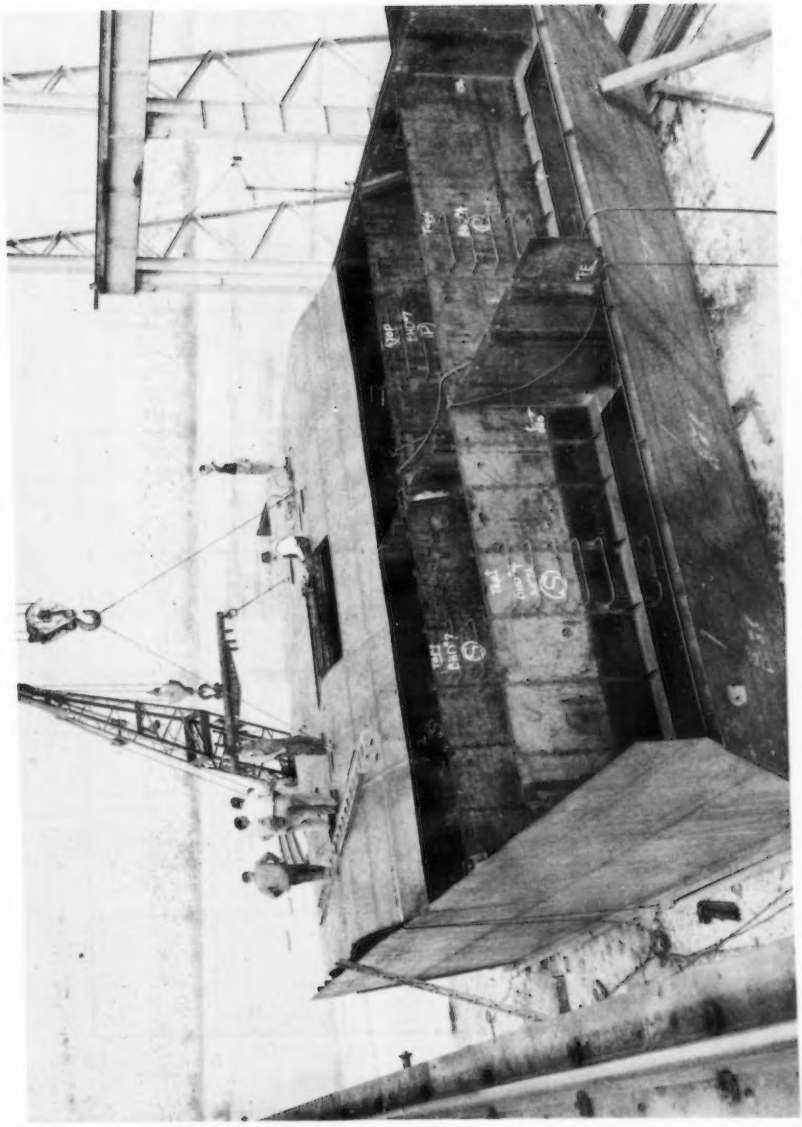
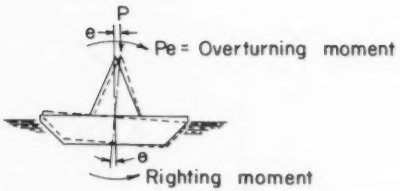


Fig. 1. Partially Completed Barge Showing Compartmentation and Bulkhead Stiffening.



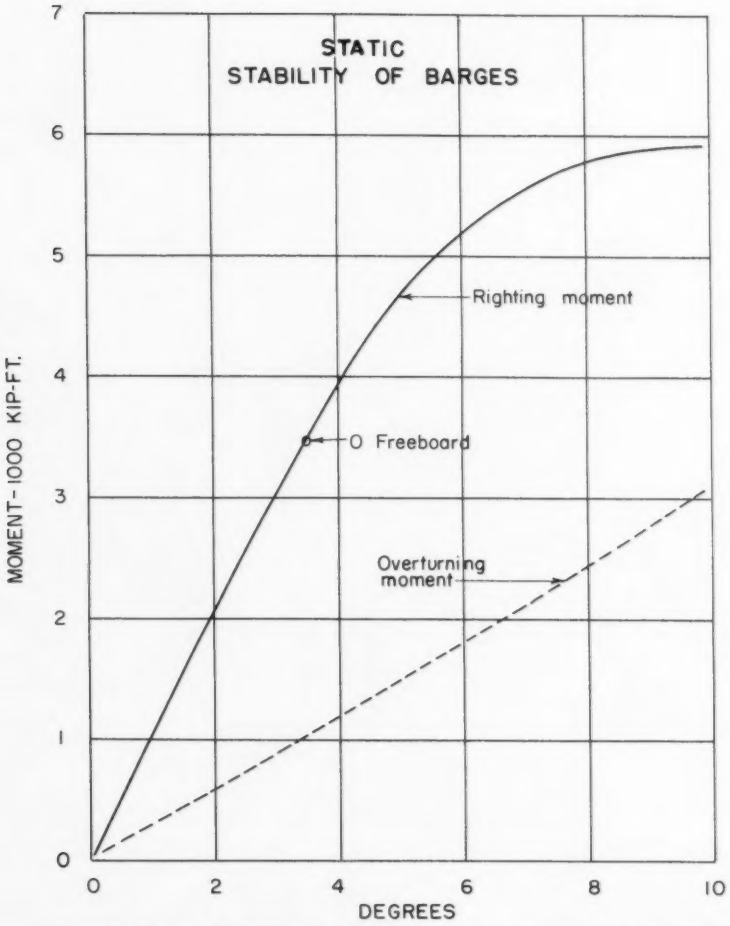


Fig. 2. Barge Stability Rotating About the Axis Through the Connecting Bridge.

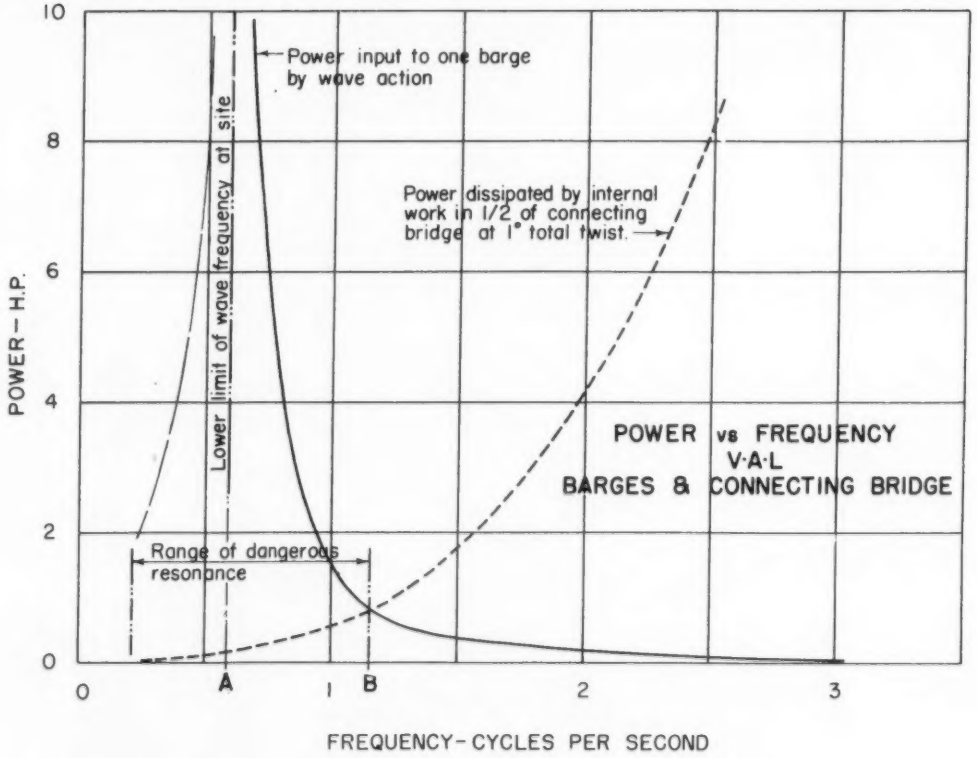


Fig. 3. Resonance Conditions for Rotation of Barge Under Excitation by Wave Action.

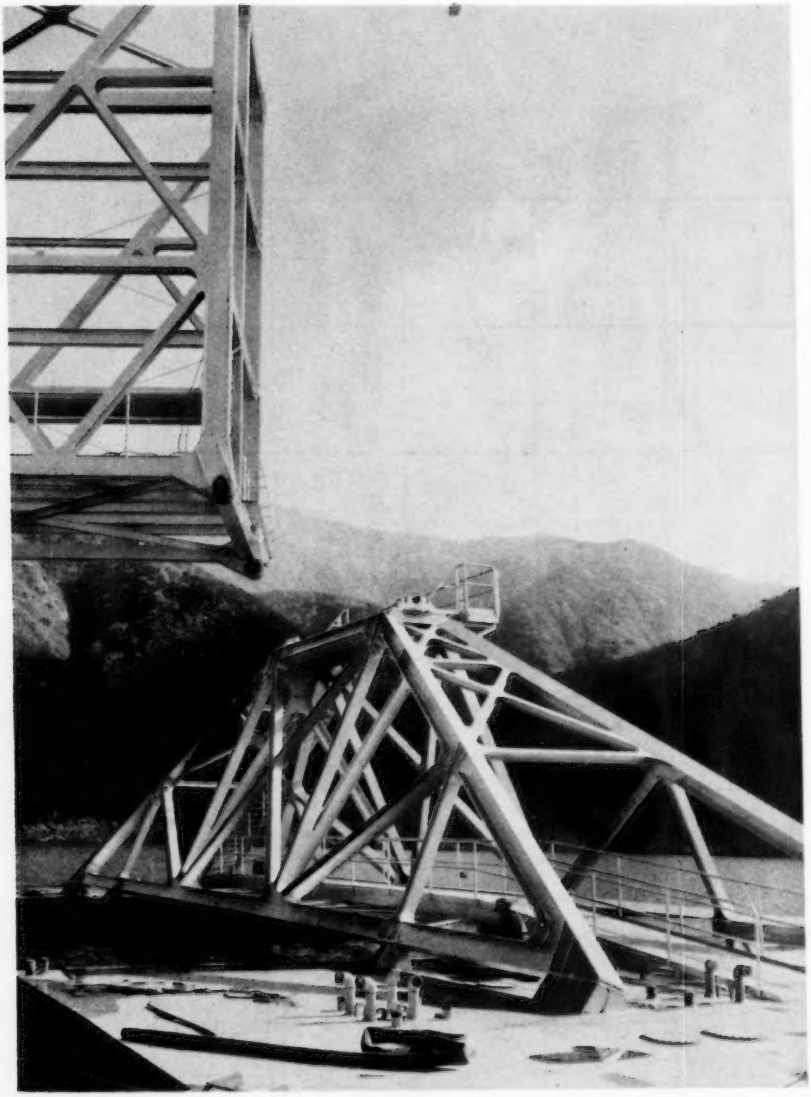


Fig. 4. Connecting Bridge Showing the Clean Appearance Obtained Through Continuity of Welding.

Fig. 5. A Complex Joint on the Connecting Bridge Involving Nine Members Entering a Common Working Point at Varying Angles.

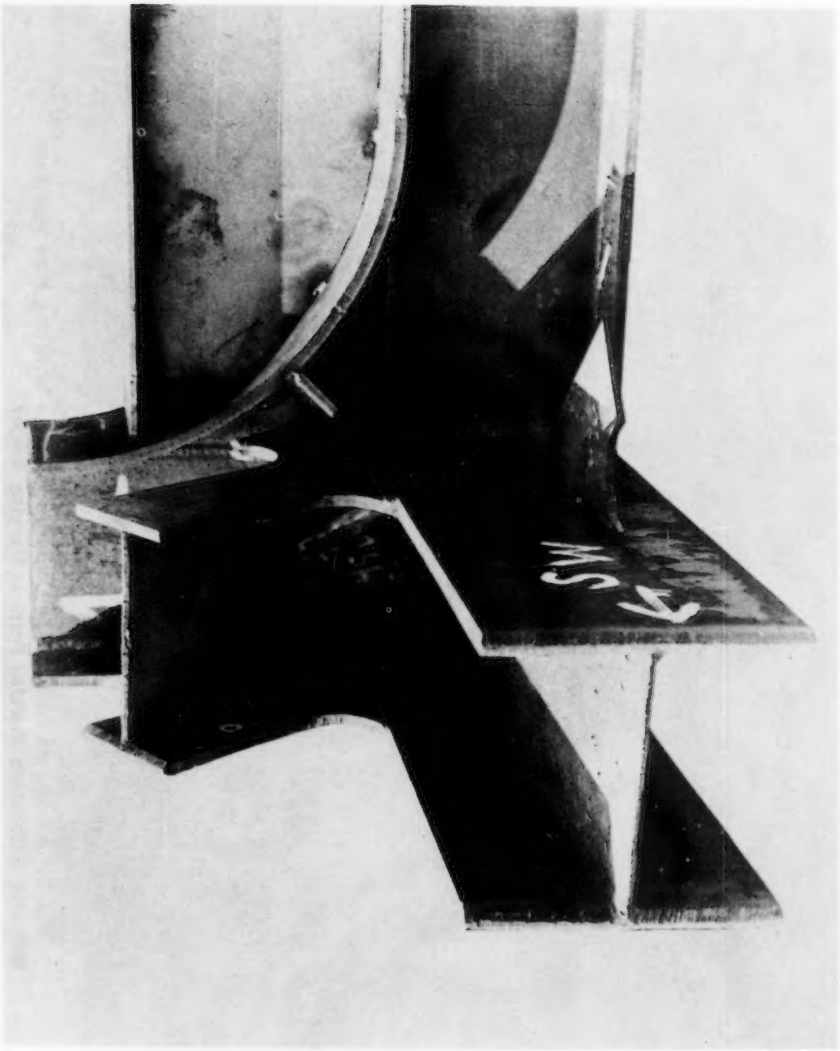


Fig. 6. Lower Chord Joint on Main Bridge Showing Filleting and Flange Continuity.

Fig. 7. Welding the Main Bridge at Assembly Area.

TABLE I -- LOADS APPLIED TO THE BRIDGE STRUCTURE OF THE VARIABLE-ANGLE LAUNCHER

Dead Load:

All weights of steel members and connection material in the bridge structure.

Total dead load of bridge ---------- 384.6 Kips

Live Load, Fixed:

All weights of superimposed structure and fittings including launching devices, tanks, walkways, and nominal live loading on deck areas.

Nominal live load ------ 25 psf

Total fixed live load on bridge ---------- 976.8 Kips

Live Load, Moving:

Inertia load

The combined weight and inertia, force of a single maximum moving load.

Maximum live load, moving ---------- 66.0 Kips

Recoil Load:

The maximum single reaction force from a launching device.

Maximum recoil load ---------- 630.0 Kips

Wind Load:

The horizontal force due to wind:

Unit loading:

On 1 1/2 times the projected structural area -	30 psf
On the projected area of the tubes ----------	18 psf
On the projected area of the tanks ----------	11 1/4 psf

Total wind load on bridge ---------- 105.2 Kips

Seismic Loading:

The horizontal force due to an acceleration of 0.10 gravity acting upon the dead load plus the fixed live load.

Maximum seismic loading ---------- 87.3 Kips

Torsional Loading:

The loads resulting from a rotation of the barge end of the truss of 0.39^{o}, the carriage end remaining fixed.

Maximum moment applied to one end of the bridge structure ---------- 1.17×10^{3}K - ft.

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Combined Loading:

Twelve different loading combinations, when the bridge structure was level and tilted were checked. A 20% increase in unit stresses was allowed for combined loading conditions.

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VARIABLE-ANGLE LAUNCHER: MECHANICAL AND ELECTRICAL FEATURES

F. L. Carlisle*
(Proc. Paper 1342)

FOREWORD

The design and construction of the U. S. Naval Ordnance Test Station's "Variable-Angle Launcher"—a unique $2,000,000 test facility at the Station's Morris Dam Torpedo Range near Azusa, California—is described in Proceedings Papers 1339 through 1343. Designed to launch various types of projectiles into the water under controlled conditions at high velocities and variable entry angles, the variable-angle launcher permits the detailed study of projectile water-entry performance. It has served as a valuable tool in developing improved air-launched torpedoes which can be released by aircraft at high altitudes and at high release speeds.

The launcher consists of a 22 1/2-in. torpedo-launching tube, 300 ft. long, mounted on a movable 300-ft., all-welded, steel bridge. The upper end of the bridge is supported on a welded structural steel carriage which rides on rails up and down the 45° slope of a peninsula jutting into Morris Dam Reservoir. The lower end of the launcher bridge is supported by a second, transverse bridge 95 ft. long, which rests on two steel barges floating in the water. The weight of the launcher and carriage is balanced by a 600-ton counterweight car which rides on rails up and down the back slope of the peninsula. The elevation angle can be varied between 10° and 40° by moving the upper end up or down the tracks on the 45° slope. The launcher can also be rotated in azimuth by adjusting the position of the barges and transverse bridge.

Projectiles are launched at velocities up to 800 ft. per sec. by means of a compressed air system. The compressed air, at 1,000 lb. per sq. in., is contained in a 500-cu.-ft., all-welded, air flask, and is released into the launcher tube by means of a quick-acting 22 1/2-in. sleeve which opens in 0.10 sec. A complex electronic system controls the launching process. Elaborate instrumentation—photographic, acoustic, and electronic—provides information on

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the position, attitude, velocities, and accelerations of projectiles during launching and water entry.

Proceedings Paper 1339 presents the need for a research facility of this sort, outlines the planning of the structure, and describes the functions and characteristics of the structural elements. Proceedings Paper 1340 describes the extensive foundation treatment required and the design of the concrete structures. Proceedings Paper 1341 presents a description of the steel structures, including the 300-ft. span, all-welded, launcher bridge—longest all-welded bridge span in the United States. Proceedings Paper 1342 discusses the mechanical and electrical features of the launcher, including the projectile-launching equipment, handling and transport equipment, operating equipment used to change the launcher angle, and test instrumentation. Proceedings Paper 1343 summarizes the actual construction of the facility, including some unusual solutions to the construction problems.

INTRODUCTION

This paper describes the unusual and interesting mechanical and electrical features of the Variable-Angle Launcher Project at the Morris Dam Torpedo Range in San Gabriel Canyon, California. The complete flexibility of this launcher which permits a variation in both vertical and horizontal angles requires a complex mechanical system to obtain this operation as well as fine electrical controls. This launcher (Fig. 1) can be most simply described as a test device for firing into water, projectiles of various sizes, shapes, and weights. The conditions affecting the missile performance at water entry can be controlled so that it is possible to duplicate the conditions prevailing when a missile is dropped or fired from aircraft.

The basic elements of the launcher can be seen in the photographs, particularly Fig. 1. The actual guns or launching tubes, as they are usually referred to, are mounted on a steel bridge structure. The lower end of this bridge is supported by two large steel barges connected by a transverse bridge structure. The upper end of the launcher bridge is supported on a 45-degree slope by a movable carriage. This carriage is connected by wire ropes to a counter-weight car mounted on a 30-degree ramp on the back side of the peninsula. This system of structures is moved by means of a triple-drum drive acting upon the wire ropes where the two ramps converge at the top of the concrete supporting structure. One drum only of the three-drum drive machinery assembly is driven. The purpose of the three-drum element was to obtain the necessary angle of wrap around the powered drum.

The floating end of the launcher is restrained from moving in azimuth by wire rope lines extending from the end of the bridge on each side to shore points on each side of the launcher center line.

This paper is confined to a discussion of the mechanical and electrical features of the launcher. The equipment required can be grouped functionally in the following categories:

1. Projectile launching equipment
2. Handling and transport equipment
3. Operating equipment used to change the angle of the launcher bridge
4. Instruments and equipment used to obtain test data.

Each of these topics will be discussed to show the design problems that were encountered and how these problems were solved.

Projectile Launching Equipment

The design specification required that provision be made for firing a wide range of sizes of projectiles. The present facilities provide two launching tubes of 22 1/2 in. and 32 in. in diameter mounted on the bridge structure. Additional launching equipment may be installed later if new requirements appear. Space for these additional launchers has been provided.

The launching tube installed at the time of the original construction is 22 1/2 in. inside diameter, and it measures 300 ft. long from breech door to muzzle. It is a smooth-bore tube consisting of 11 sections, each 25 ft. long, plus Y-joint and breach sections. Bolted flanges join the sections at the launcher bridge panel points. The tube is supported by adjustable tie rods from the tube flanges to the transverse rigid frames at each panel point of the bridge trusses.

The propulsive medium used for launching is compressed air. A 500-cu. ft. flask located directly over the tube supplies compressed air at any pressure up to 1000 psi. The compressed air is introduced into the tube from the air flask through a Y-joint located in the breech section of the tube. Release of air from the air flask is accomplished by a unique valve.

In order to obtain a high propulsive efficiency, it was necessary to provide a valve which would open a port area equivalent to the area of the launching tube cross section (400 sq. in.) in one-tenth of a second. To meet these requirements a 22 1/2-in. diameter sleeve valve (Fig. 2) was designed and built into the air flask itself. The valve cylinder extends from the bottom of the air flask to the top. The valve ports are located in the central portion of the cylinder, and the valve piston (Fig. 3) covers the ports in the closed position. A connecting rod extends from the valve piston to an auxiliary piston outside the main air flask. In order to accomplish the very rapid opening which is desired, the lifting force of the auxiliary piston is augmented by the pressure of air from the flask itself acting on the bottom of the main valve as soon as the ports are cracked. Oil damping is provided to decelerate the valve piston at the end of its stroke. The space directly over the valve is filled with oil. Varying orifice restriction is achieved by a conical buffer attached to the connecting rod which enters a circular orifice producing an increasingly restricted oil passage as the valve moves upward.

Firing is accomplished by admitting air into the auxiliary cylinder below its piston and thereby raising the valve piston through the connecting rod. As soon as the lower end of the valve piston clears the lower edge of the ports in the valve cylinder, air rushes in and a swiftly rising pressure is exerted on the bottom of the valve piston as pressure builds up behind the projectile. The piston accelerating force has a maximum value of nearly 400,000 lb. This results in a very rapid acceleration of the piston. As the valve ports approach the fully opened position, the oil flow upward ahead of the piston is increasingly throttled, and the piston is decelerated to a stop within a few inches. During the throttling period, the oil pressure between the piston and the orifice rises to a maximum of about 2,000 psi and then remains nearly constant during the main portion of the deceleration period. The oil ejected from the orifice is forced into a circular path by vanes in the oil receiver and its kinetic energy is dissipated.

Three double seal type rings are used on each end of the valve piston to prevent air leakage prior to firing. During the initial period of operation of the equipment, very little air leakage was experienced at high flask pressures, but leakage was found to be appreciable at low pressures that were apparently insufficient to produce good seating of the rings. To correct this condition, rubber "0" rings were placed behind the middle piston rings of the main valve piston. This measure is almost completely effective in controlling air leakage. The frictional drag of the piston rings is held to a minimum by high pressure injection of grease through the walls of the valve cylinder between the piston rings prior to each firing.

The auxiliary air cylinder which initiates the opening of the main air release valve is operated by air stored in a small auxiliary flask. The auxiliary air flask is supplied by the same compressor as the main air flask. The pressure in the auxiliary air flask, however, is constant for all launchings regardless of the pressure that is used in the main flask.

To preclude premature firing, auxiliary air flask pressure is maintained on the top of the auxiliary piston. The air above the auxiliary piston is vented a few seconds before firing. The vent port below the auxiliary piston is then closed and the firing pressure is introduced.

Several misfires took place during the testing period of the launching equipment. These were due to very high air leakage around the auxiliary cylinder piston rings from the safety side to the fire side of the auxiliary piston. The vent valve, though open, was apparently too small to permit rapid venting of the fire side of the piston. The pressure due to air leakage became high enough that, at the time of venting of the safety air, the pressure of air on the fire side would initiate immediate firing without the opening of the fire valve. Rubber "0" rings were added behind the middle piston rings of the auxiliary piston to stop the air leakage causing this condition. This measure, coupled with the installation of a larger vent valve on the fire side of the auxiliary piston, effectively prevented any further misfires.

Supplying air for the operation of the launcher presented a serious problem. Piping high pressure air from a movable bridge was thought to be dangerous. However, the locating of a large compressor on the steel structure was likely to lead to vibration problems. The decision was made to locate the compressor on the steel carriage which supports the bridge, and to work out corrective measures to control vibration.

The compressor selected is a 150-hp Y-type, 4-stage model. It is driven by a 2,400-volt synchronous motor supplied with power by a flexible cable which is plugged into the nearest outlet box along the west side of the launcher slope. Vibration proved to be an even greater problem than had been anticipated. Initial operation of the compressor produced vibration of 1/8-in. amplitude in three 12 in. wide flange beams supporting the compressor, and some steel hand railings around the compressor platform were excited to amplitudes of 3 in. or more. These large vibration amplitudes were clearly the result of resonance between the natural vibration frequency of the compressor platform and the pulses arising from the unbalanced rotating assembly in the compressor. The natural frequency of the platform system was determined by applying a vibratory load of variable frequency and measuring the amplitude of the resulting vibrations. The platform system has a natural frequency of 595 vibrations per minute while the energy pulse of the compressor occurs at a frequency of 600 cycles per minute corresponding to the 600 rpm speed of the 12-pole synchronous motor.

The most promising approach to the vibration problem was to counteract the unbalance in the compressor by tuned vibration dampers. The modes of vibration were determined by test. Four spring bars were then attached to the base of the compressor in the plane of the Y. Two springs extended outward horizontally, and two more were hung vertically from the bottom of the compressor base. Five hundred pound weights were mounted on each of these springs. These weights could be varied in position near the end of the springs to permit tuning. By tuning these spring masses, virtually all the vibration of the compressor was eliminated. To protect other equipment on the same platform, the compressor was isolated from the platform by rubber shock mounts.

Although the vibration dampers were successful in eliminating the vibration, it was found that the spring bars were not able to withstand the oscillating stresses for reasonable lengths of time. Cracks due to fatigue failure appeared in the bars near the support and these cracks changed the frequency of the spring necessitating shut-down and replacement. This maintenance became excessive and the compressor was moved to a platform adjacent to the carriage track and the air piped up and down the slope with service provided at intervals. A flexible high pressure hose connects these outlets to the air flask.

A very elaborate interlock system has been incorporated in the launching circuits to prevent misfires, accidents, and loss of data. The interlocks insure that all operations necessary for firing are done in the proper sequence. Firing is prevented by the interlocks if the breech door pin is not completely secured or if the carriage is not properly anchored on the launcher slope.

The launching of a missile and operation of all test equipment is under the control of a test operator. The fire control equipment is located in a small reinforced concrete building separate from the launcher structure but strategically located to provide maximum visibility of the launcher and at the same time provide protection for personnel in case of accident. The operator can call for any desired combination of cameras and other instruments by means of a control console, and he receives signals in the form of indicator lights on this panel when the instruments are ready.

Handling and Transport Equipment

The problem of transport involves the moving of projectiles, equipment, and personnel from the shop level near the middle of the launcher ramp to the bridge support carriage at whatever elevation it is located; the moving of projectiles and equipment on the support carriage deck; the loading of projectiles into the launching tube; and the moving of equipment and personnel on the counterweight ramp.

A level platform car provides transport up and down the 45-degree launcher slope (Fig. 4). It has a permissible load limit of four tons. The car is moved on the slope by a 1-in. wire rope running up the slope and over an idler sheave to a single-drum winch.

A solenoid brake on the high-speed shaft of the winch speed reducer serves for operational braking. It is applied automatically when power is shut off or in case of power failure. Emergency braking is provided by an elevator-type centrifugal overspeed brake on the car. The emergency brake acts on a stationary auxiliary cable which parallels the drive rope. It is actuated by

excessive speed of the car or by slackening of the drive rope. It can also be applied manually from the car deck.

Projectiles and equipment on the bridge-support-carriage deck are handled by a 3-ton overhead crane (Fig. 4). An extended rail makes it possible to run the hoist out over the side of the carriage and above the projectile car for unloading from the car and transfer to the carriage deck.

Projectiles are loaded into the launching tube by a cable-driven ram which pushes the projectile along a supporting trough and into the tube. The cable is driven by a long hydraulic cylinder. The projectile is aligned with the launching tube by pivoting the loader frame on the breech of the tube and then raising the loader and projectile to the tube angle.

Transport of personnel on the 30-degree counterweight slope is by a car similar to, but smaller than, the car on the launcher slope. It has a capacity of 1 ton. Hoisting and braking systems are similar to those provided for the projectile car. The car can be controlled from any one of three points; at the top, middle, and bottom of the counterweight slope.

Operating Equipment Used to Change the Angle of the Launcher Bridge

The launcher bridge and tube can be adjusted to angles between 0 and 40 degrees with the horizontal by moving the carriage supporting the inward end of the launcher bridge up or down the 45-degree launcher ramp. The structure is moved by a three-drum traction drive acting or the sixteen 2 1/8-in. wire ropes which connect the bridge-support carriage and the counterweight car. This drive (Fig. 5) is located on a small level platform at the top of the two concrete ramps. The drive has three cast-steel grooved drums, each 84 in. in pitch diameter. The sixteen 2 1/8-in. wire rope lines leading from the launcher bridge support carriage pass over the lower drum nearest the launcher slope, thence under and around the lower drum nearest the counterweight slope, under the top drum, around it, and down the counterweight slope to the counterweight car. The lower drum nearest the counterweight slope is used as the drive drum. By using a three-drum arrangement it was possible to get 270 degrees of wrap angle on the driving drum. At normal full-load rating, the drive drum can apply a force of 120,000 lb. to move the launcher.

A 120-tooth bull gear is bolted directly to the flange of the driven drum. The pinion shaft is coupled to a triple-reduction speed reducer through a gear-type coupling. The total reduction from motor to drum is 966 to 1. The driving motor is a 75-hp series-wound 230-v direct-current motor with a rated speed of 850/1065 rpm at full load. This gives a maximum running speed of approximately 20 ft. per minute.

The main drive power required to move the launcher varies with the angle of the launcher, friction in the system, and the degree of unbalance existing between the bridge and the counterweight. In order to meet the range of torque requirements and provide smooth starting, a modified Ward-Leonard variable-voltage control system was designed for the main drive power supply. An amplidyne generator is used to supply the main generator field. Use of the amplidyne offers two advantages in this application: (1) Control currents of very small value are possible, that is, less than 0.1 ampere. (2) Use of three fields on the amplidyne permits automatic limitation of both torque and speed of the drive motor, thereby making the system self-protecting.

During a launching, the carriage is locked to the rails by four 7-in. pins.

The torque-control system makes it possible to stop the carriage precisely at the correct location to permit sliding the pins into the holes in the rails (Fig. 6). Moreover, the torque is controlled so smoothly that the carriage can be started or stopped without any jolting or sensation of acceleration.

A small control house on the top level of the concrete structure beside the main drive is the usual operating center for moving the launcher. A portable control unit which plugs into any of several receptacles along the launcher ramp can also be used, when needed, to provide control from points where the carriage position can be observed closely to align the locking pins. Electric power is supplied from 16,500-v commercial lines, and reduced to 2,300 volts in a 750-kva substation. Transformers reduce the voltage again to 440 volts. The direct current for the main drive motor is supplied by a motor generator set consisting of a 125-hp 550-v induction motor and a 100-kw 250-v direct current generator.

Movement of the outer end of the launcher bridge is controlled by the windstay lines. They are five-part one inch wire rope lines extending from the end of the launcher bridge on each side to anchor points on the shore 265 ft. each side of center line. The live ends of the wire rope lines were brought in to winches near the base of the concrete ramp.

The two windstay winches and their attendant rigging have two functions: (1) They serve to restrain the bridge from movements in azimuth due to wind loads, regardless of the vertical angular position of the bridge. In this respect they are simply adjustable anchors to prevent rotation of the bridge. (2) They serve to swing the bridge into azimuth positions other than directly down range. The upper end of the bridge has a vertical pivot-bearing at its connection to the bridge support carriage which permits such movement. Movements of 22 1/2 degrees off the normal range line in azimuth for the purpose of making studies of ricocheting projectiles are possible.

The two winches are of simple, single-drum design. The drive motors are wound rotor with variable field resistance. To swing the bridge to the left, the field resistance is increased on the right-hand windstay winch motor and held to a lower value on the left-hand motor. The left-hand motor then exerts a greater torque than the right hand and overhauls it, pulling the right-hand line out against the motor torque. Very smooth control is obtained with a high degree of safety. The windstay lines are never allowed to become slack.

Fifty-horsepower, 440-volt, 900-rpm motors are used on the winches. A double-reduction speed reducer provides a reduction to the drum of 169 to 1. Service braking is on the high-speed shaft of the speed reducer and consists of a conventional solenoid release band brake. A pawl acting on a ratchet on the winch drum flange locks the drum during standing periods. Controls for the windstay winches are located in the operating house at the top of the launcher ramp.

Instruments and Equipment Used to Obtain Test Data

The fundamental reason for building the Variable-Angle Launcher was to obtain data on the behavior of projectiles as they enter the water at different angles and velocities. Instrumentation and recording are required, not only to provide the projectile behavior data, but also to provide information on the operation of the launcher and to coordinate control of launchings and instrumentation equipment.

Data regarding projectile behavior can be considered under three major headings:

1. Airflight. During airflight the forces acting on the projectile are small, and it is necessary to determine only the velocities and angles just prior to water entry. The following factors need to be measured for each launching: entry angle, entry velocity, pitch and pitch velocity at entry, yaw and yaw velocity at entry, and roll and roll velocity at entry.

2. Water entry. During water entry, impact forces and steady-state forces are large and difficult to determine, and act principally on the nose of the projectile. Measurements required include the deceleration, which has longitudinal and transverse components; the whip, or total angular velocity change at entry; and stresses and strains produced in the various parts of the projectile. The last may involve measurement of permanent deformation, or determination of structural damage to the projectile.

3. Underwater trajectory. The underwater trajectory may be divided into the cavity stage and the steady-running condition subsequent to the shedding of the cavity. As the missile enters the water at high velocity a cavity forms around it, the size and shape of the cavity depending upon the size and shape of the nose of the missile and the velocity. While the missile is traveling in the cavity, its motion is influenced by large forces applied to the nose of the projectile and any other parts that come in contact with the cavity wall. The missile decelerates rapidly and the cavity soon collapses. The missile then continues its course, and it may be propelled and guided for the remainder of its underwater trajectory. The information desired is a complete plot of position versus time, or the underwater path of the projectile, in three dimensions, with the velocity at each point known.

Another type of data, in addition to those concerning projectile behavior, consists of information regarding the operational behavior of the parts of the launcher itself. Measurements of this type are of particular importance when a new technique or new type of launching is tried, as, for example, a higher launching pressure. Such measurements were, of course, needed in largest numbers immediately after the launcher was placed in operation.

Data concerning the behavior of parts of the launcher that most frequently have been of interest include the following:

1. Launching valve operation and pressures.
2. Pressure variation with time in the launching tube, pressure tank, Y-joint, and breech.
3. Stresses and deformations in the various components during launching, particularly the stresses in the Y-joint, breech, and air tank.
4. Vibration of the large compressor and tuning of the vibration dampers.

To obtain useful data from launchings, devices are required both to pick up the desired information and to make a permanent record in a form which later can be interpreted. In some cases one device, such as a camera, performs both functions; in others, separate devices are used for data pickup and recording, sometimes with one or more intermediate links.

The camera is the most important tool in recording the state or change in state of the missile during its airflight. High-speed motion-picture cameras are located over the water-entry point, to the side of the entry and to the rear, to document the airflight of the projectile and the first phase of water entry.

These are supplemented by plate cameras. The principal trajectory camera is a side-view plate camera with a rotating shutter. This camera records the image of a bright flare on the tail of the projectile as a series of dots on a single film. This record provides the best air trajectory data as well as velocity versus time data.

The underwater trajectory of the missile is followed by means of an array of hydrophones for sound detection (Fig. 1). Explosive caps are fired at short intervals within the projectile after it enters the water by means of an automatic cap-firing mechanism. The sounds of the explosions are picked up by a series of hydrophones arrayed in a fixed pattern on each side of the range line. The sound picked up by each hydrophone is recorded as a pip on an oscillograph film. Since the time for the sound to travel from the projectile to each hydrophone varies with the distance, it is possible to determine mathematically the position of the missile at the time of each cap explosion from the distance between pip positions on the oscillograph film. In actual practice the equations are solved by a special mechanical computer.

In addition to these primary end organs for procuring data, facilities are provided for making pressure measurements during firing, for taking strain gage measurements, and for measuring velocity and acceleration in the launching tube.

All measurement systems are coordinated by a master timer. The heart of the timer is a 1000-cycle tuning fork. The signal from this is supplied to all cameras and oscillographs simultaneously, so all records show the same time reference, and separate instruments are not required to be synchronous. The tuning fork operates continuously and is compensated for temperature variations so that consistently high accuracy is obtained. A unit containing seven 2-in. cathode-ray tubes is placed in the field of view of an auxiliary lens in each camera which focuses the image on a corner of each frame of film. Four of the cathode-ray tubes are used as indicators for a decade system in which the spot in the first tube moved clockwise around the tube screen in ten steps of 1-sec. interval. The second, third, and fourth tubes show 0.1, 0.01, and 0.001 sec. intervals respectively. The time, indicated simultaneously on all camera units and at control stations, is started from zero at the initiation of each launching. The other three tubes are used to indicate the last three digits of the launching number.

The controls for the launching valve, the oscillographs in the recording station, and the cameras at the various remote stations can be operated either manually or by an automatic sequencing system. For most launchings, there are so many events which must occur in proper time sequence that the automatic system is required. The sequencing system consists of the following equipment: (1) A pulse generator (Fig. 7) and a group of selector units which can be used to start and stop the launching controls and instruments at any desired time during the 10-sec. interval after the launching operator has started the pulse generator. (2) More precise electronic timers which can be started by the initial motion of the projectile in the tube and which provide for delay and operating times up to 2-sec. duration. (3) Auxiliary motor-driven timers which can be used for instruments requiring longer than 10 sec. of operation; they can be set for any time up to 2 minutes.

These instruments provide more complete data on the water-entry behavior of missiles than can be obtained in range tests where aircraft are used and permanent controls and recording instruments cannot be employed. Data obtained from several types of instruments located in different places are

readily correlated on an accurate time scale. Operation of the instruments is coordinated from a central control house and the sequence of events is automatically controlled. All of these features of the test operations combine to yield a large amount of significant information regarding the missiles water-entry characteristics with a reasonably small expenditure of time and effort on the part of test personnel.

Fig. 1. The Variable-Angle Launcher, Hydrophone Array, and Camera Stations.

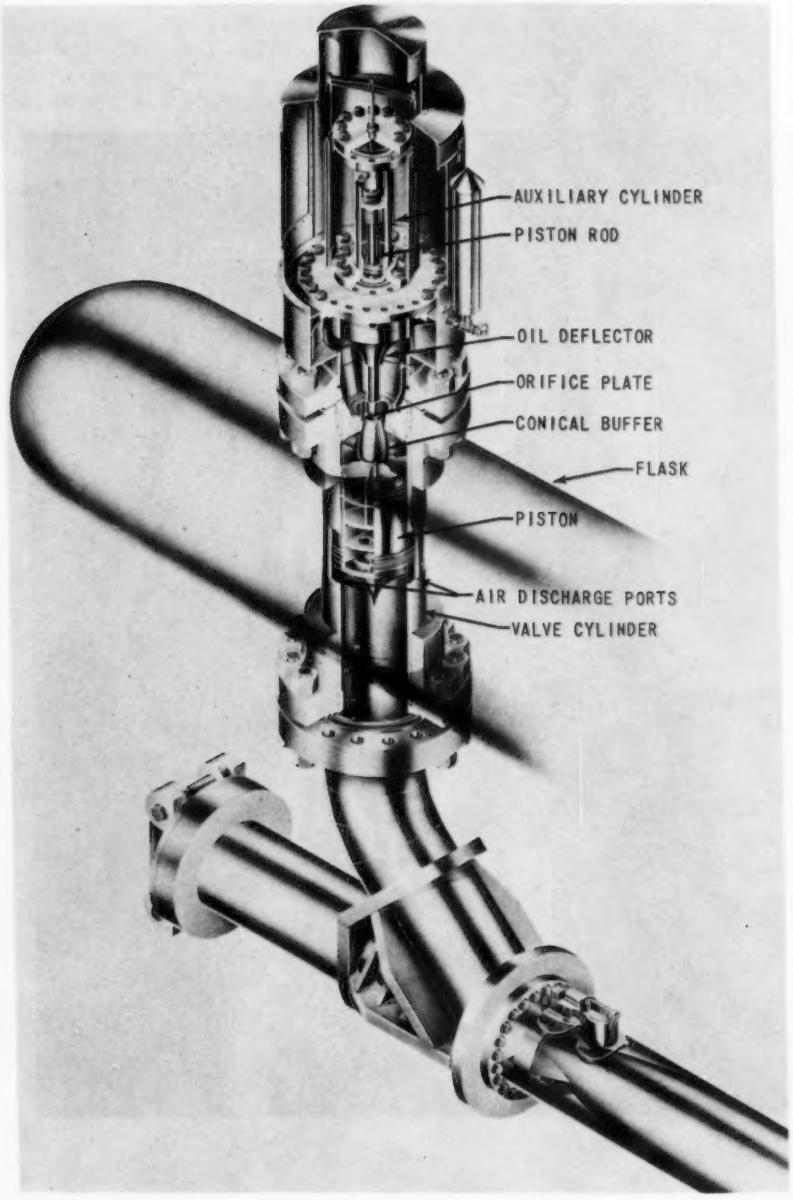

Fig. 2. Launching Valve of the Variable-Angle Launcher.

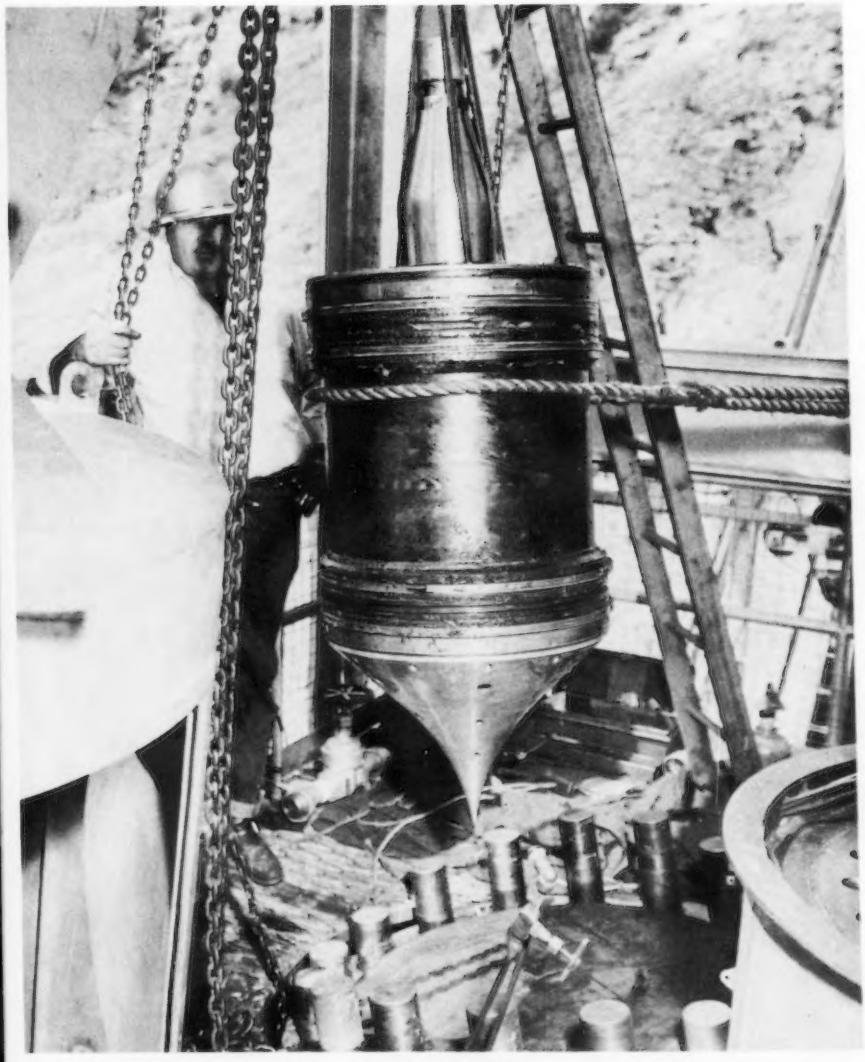

Fig. 3. Main Piston and Conical Buffer of the Launching Valve.

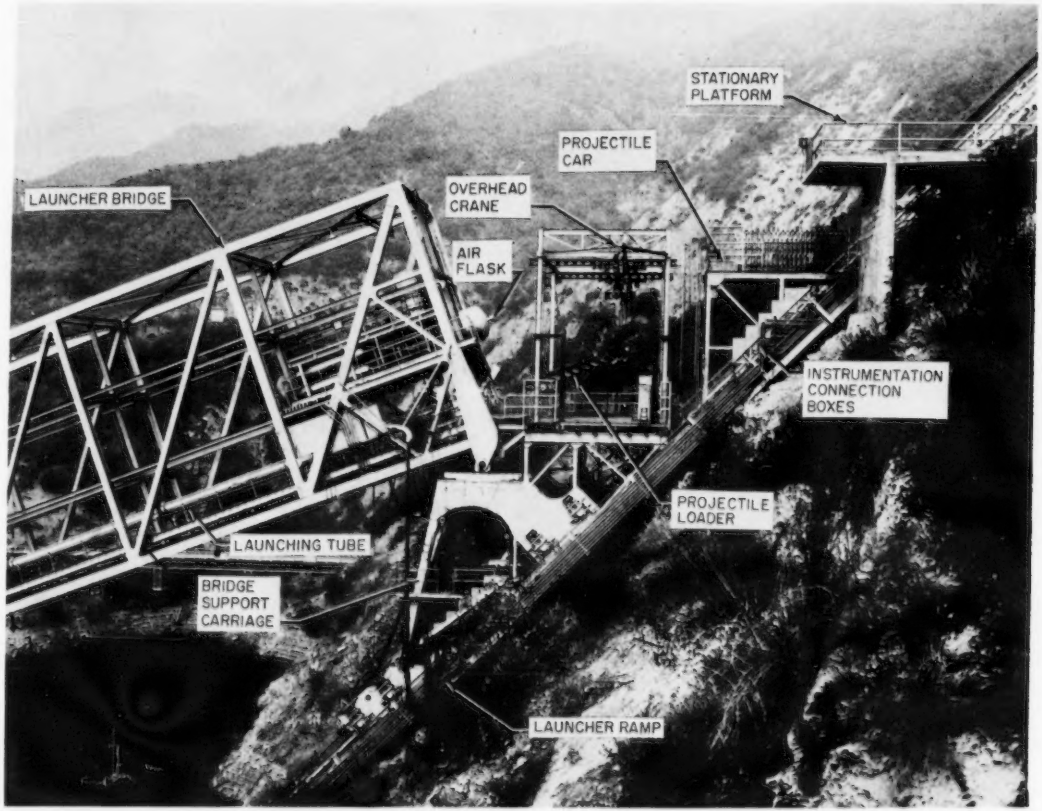

Fig. 4. Handling and Transport Equipment on the Launcher Slope.

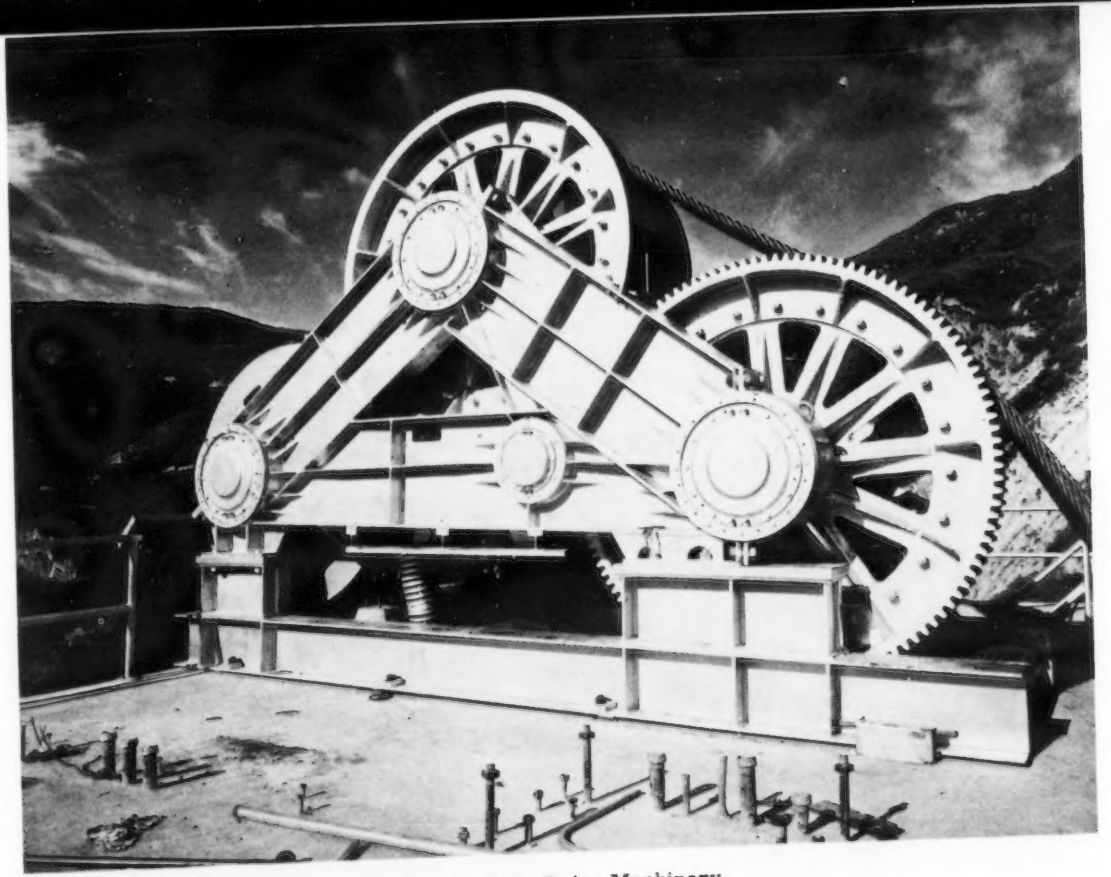

Fig. 5. Main Drive Machinery.

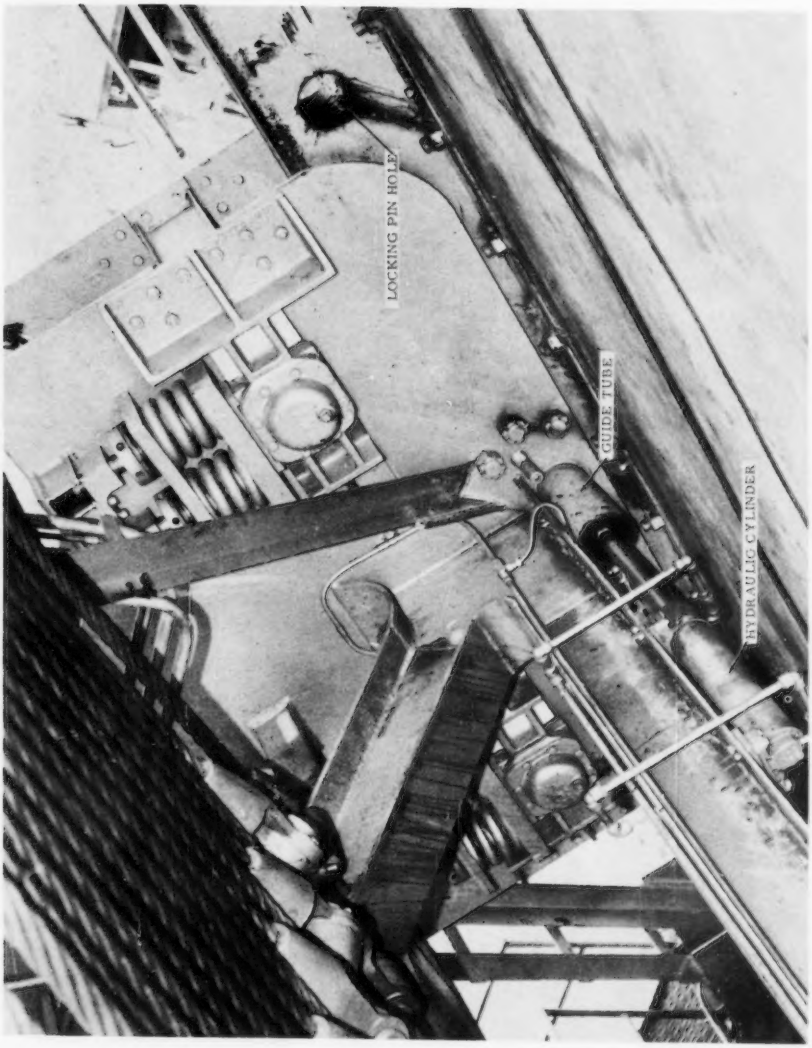

Fig. 6. Carriage Upper Wheel Assembly Showing Locking Pin and Hydraulic Drive Cylinder.

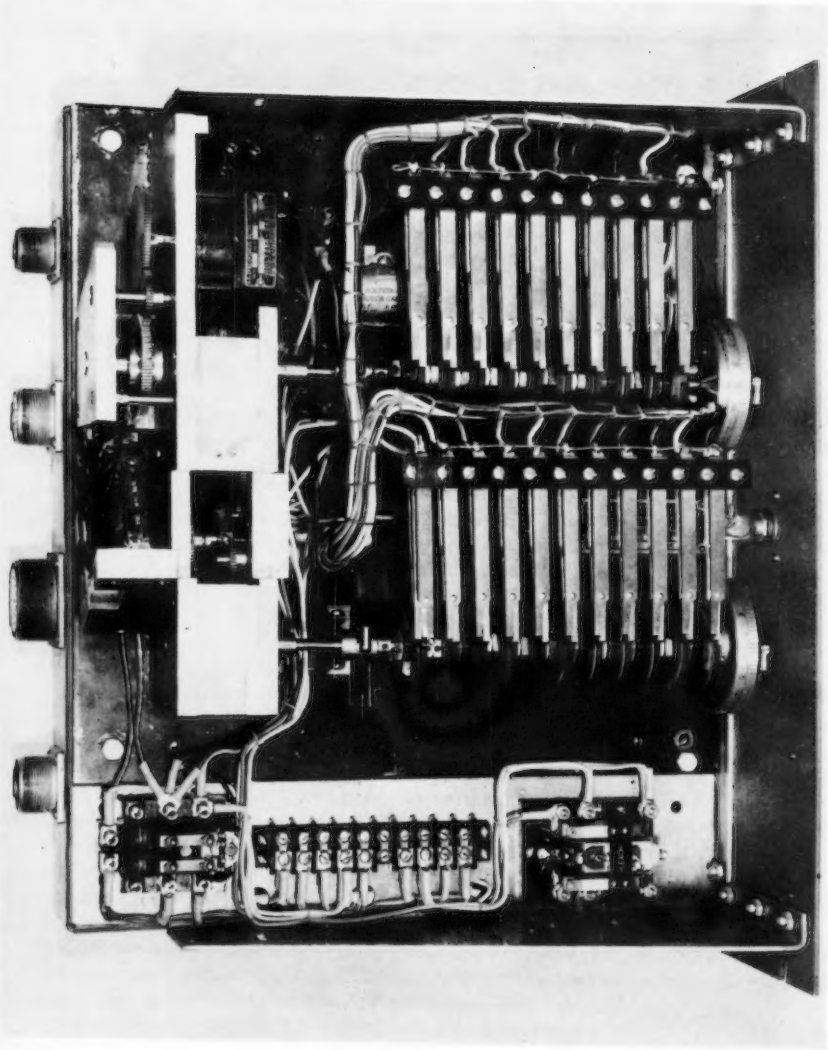

Fig. 7. Sequencing System Pulse Generator.

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VARIABLE ANGLE LAUNCHER: CONSTRUCTION

Arthur C. Bravo*
(Proc. Paper 1343)

FOREWORD

The design and construction of the U. S. Naval Ordnance Test Station's "Variable-Angle Launcher"—a unique $2,000,000 test facility at the Station's Morris Dam Torpedo Range near Azusa, California—is described in Proceedings Papers 1339 through 1343. Designed to launch various types of projectiles into the water under controlled conditions at high velocities and variable entry angles, the variable-angle launcher permits the detailed study of projectile water-entry performance. It has served as a valuable tool in developing improved air-launched torpedoes which can be released by aircraft at high altitudes and at high release speeds.

The launcher consists of a 22 1/2-in. torpedo-launching tube, 300 ft. long, mounted on a movable 300-ft, all-welded, steel bridge. The upper end of the bridge is supported on a welded structural steel carriage which rides on rails up and down the 45° slope of a peninsula jutting into Morris Dam Reservoir. The lower end of the launcher bridge is supported by a second, transverse bridge 95 ft. long, which rests on two steel barges floating in the water. The weight of the launcher and carriage is balanced by a 600-ton counterweight car which rides on rails up and down the back slope of the peninsula. The elevation angle can be varied between 10° and 40° by moving the upper end up or down the tracks on the 45° slope. The launcher can also be rotated in azimuth by adjusting the position of the barges and transverse bridge.

Projectiles are launched at velocities up to 800 ft. per sec. by means of a compressed air system. The compressed air, at 1,000 lb. per sq. in., is contained in a 500-cu.-ft., all-welded, air flask, and is released into the launcher tube by means of a quick-acting 22 1/2-in. sleeve which opens in 0.10 sec. A complex electronic system controls the launching process. Elaborate instrumentation—photographic, acoustic, and electronic—provides information on the position, attitude, velocities, and accelerations of projectiles during launching and water entry.

Proceedings Paper 1339 presents the need for a research facility of this

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sort, outlines the planning of the structure, and describes the functions and characteristics of the structural elements. Proceedings Paper 1340 describes the extensive foundation treatment required and the design of the concrete structures. Proceedings Paper 1341 presents a description of the steel structures, including the 300-ft. span, all-welded, launcher bridge—longest all-welded bridge span in the United States. Proceedings Paper 1342 discusses the mechanical and electrical features of the launcher, including the projectile-launching equipment, handling and transport equipment, operating equipment used to change the launcher angle, and test instrumentation. Proceedings Paper 1343 summarizes the actual construction of the facility, including some unusual solutions to the construction problems.

INTRODUCTION

This is the last of a series of papers describing the unique ordnance testing device called the Variable-Angle Launcher. Previous papers described the launcher and its design; this one deals with its construction.

General Tire and Rubber Company of California, under a Bureau of Ordnance contract for ordnance manufacturing and service, acted as the prime contractor. The project was divided into a number of phases and subcontracted on a bid basis according to the type of the work involved.

Careful organization of the work was necessary to permit the simultaneous operation of several contractors in the limited working areas. Factors involved were coordination of work being accomplished in one location by more than one contractor, heavy equipment and material movement and storage, means to avoid disrupting research programs in progress, required sequence and timing of operation, and contract time limits.

The concrete structures described in this article include the 30° counterweight slab on the back slope of the hill, the main cellular structure at the crest of the hill, and the 45° launcher slab on the front slope. The steel structures include the barges, connecting bridge, launcher bridge, counterweight car, and carriage.

Concrete Structure of the Variable-Angle Launcher

The natural condition of the foundation for the concrete structure and the methods employed to stabilize the foundation were described in Proceedings Paper 1340.

Counterweight Slab

The counterweight slab distributes the wheel loads of the counterweight car to the foundation. The plans for the slab permitted the use of reinforced concrete or reinforced gunite; gunite was chosen because the bids showed it to be cheaper. It was used on the portion of the slope below the cellular structure.

In construction of the slab, the overburden was first removed from the slope by hand methods. Plywood forms were then placed for sides and steps. After the form work was completed, reinforcement was placed. The mixer, compressor, compression chamber, and materials were located on the edge of

the bank just west of the slope. Sand and cement were mixed at this location in two-sack batches and transported to the compression chamber by means of a chute. Water required was obtained from a storage tank at the site and was applied to the nozzle at a pressure which varied from 45 to 74 psi. The mix used consisted of one part of cement to 4 1/2 parts of sand.

In an effort to keep the working surface free of rebound, the contractor chose to start guniting from the top of the slope. But despite his efforts, rebound accumulated on the slope. Placing the gunite was made especially difficult because of the heavy mat of reinforcing steel and wood templates used for spacing the rail anchor bolts. (Fig. 1) A total of 210 cu. yd. of gunite was placed with a minimum thickness of 18 in. Curing was maintained for six days by water sprayed on the slope.

It was expected that the slab gunite would meet the specified strength of 3000 psi at 28 days inasmuch as the gunite test cylinders made during the placing of the slab tested satisfactorily. The test cylinders, 6 in. diameter and 12 in. long, were shot into a 1/2-in. mesh hardware cloth cylinder. The cylinders indicated an average 28-day strength of 3840 psi.

Four inch cores taken from the cured slab indicated an average strength of 2100 psi at an age in excess of 28 days and a density of 137 pcf. The cores also showed a deficient bond between layers of gunite and between gunite and reinforcing bars, as well as extensive occurrence of sand pockets. A view of the cores is shown in Fig. 2. Cores which contained obvious surface deficiencies were not tested.

The foundation is sufficiently strong that uniform pressure under the slab is not required. Despite the deficiencies of the gunite, it was thought that the strength of the slab was sufficient to serve its purpose, and the type of failure that might occur would be progressive cracking or disintegration which could be observed. Such failure of the slab would not endanger the structure, and repairs could be made at a later date if necessary. During replacement, a test program could be maintained with nominal limitations of launching angle. In the light of the Government's urgent need for the completed project, the slab was accepted as constructed.

The rails chosen for the counterweight track were 90 lb. per yard and the track was made standard gage. The rails are anchored by pairs of one-in. bolts spaced on 3-ft. centers. After the curing of the gunite, the rails were aligned and grouted into place.

Main Structure

The main concrete structure is a cellular continuation of the slopes of the launcher ramp and the counterweight ramp. It also forms the structural support for the main drive machinery, houses various electrical machinery and instruments and furnishes laboratory space. Cantilever balconies provide access to the launcher ramp from the main structure at several points. Walls of the cells were 12, 18, and 24 in. in thickness depending upon the loading. Continuous footing for each side is 10 ft. wide and with a maximum depth of 7 1/2 ft. A considerable quantity of steel conduit for electrical and instrumentation wiring are incorporated in the various walls and slabs.

The excavation for the structure was accomplished by a 3/4-yd. shovel and dump trucks. Benches for footings were hand-excavated using pneumatic tools. Approximately 19,000 cu. yd. of excavated material was hauled 1/8 of a mile and dumped into a ravine.

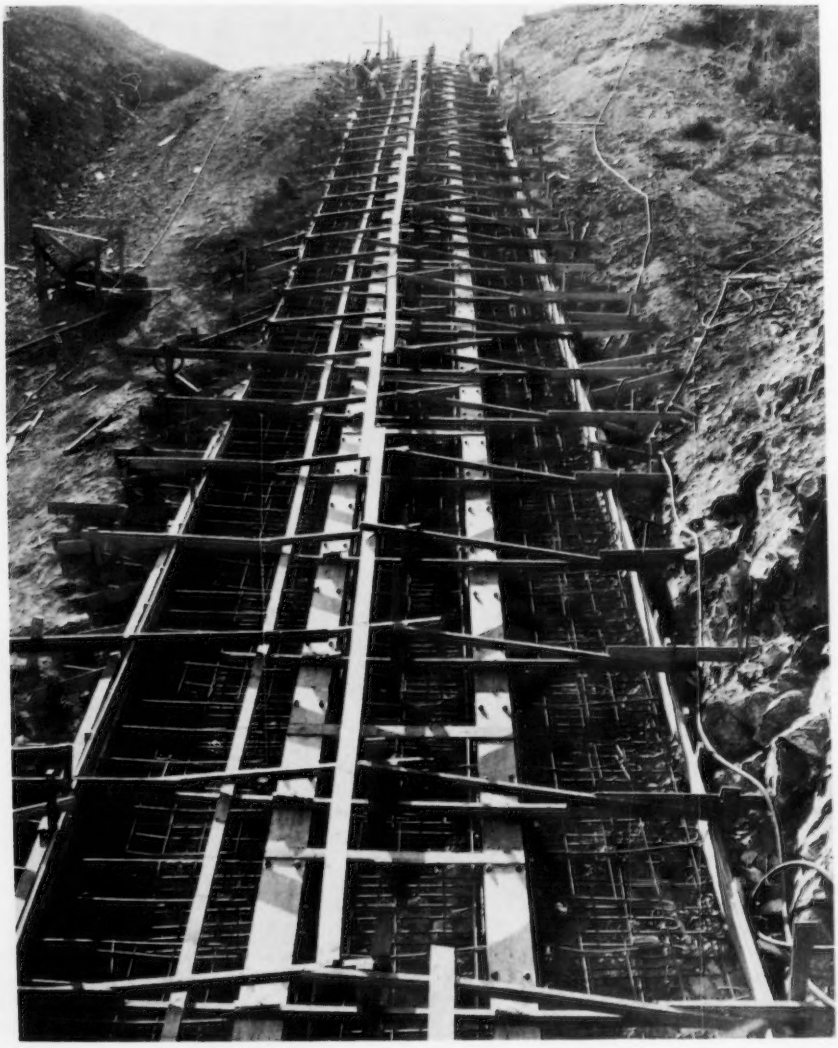

Fig. 1. The Counterweight Slope Showing the Steel Reinforcement and Forms in Place Prior to Guniting and the Completed Slope After Guniting.

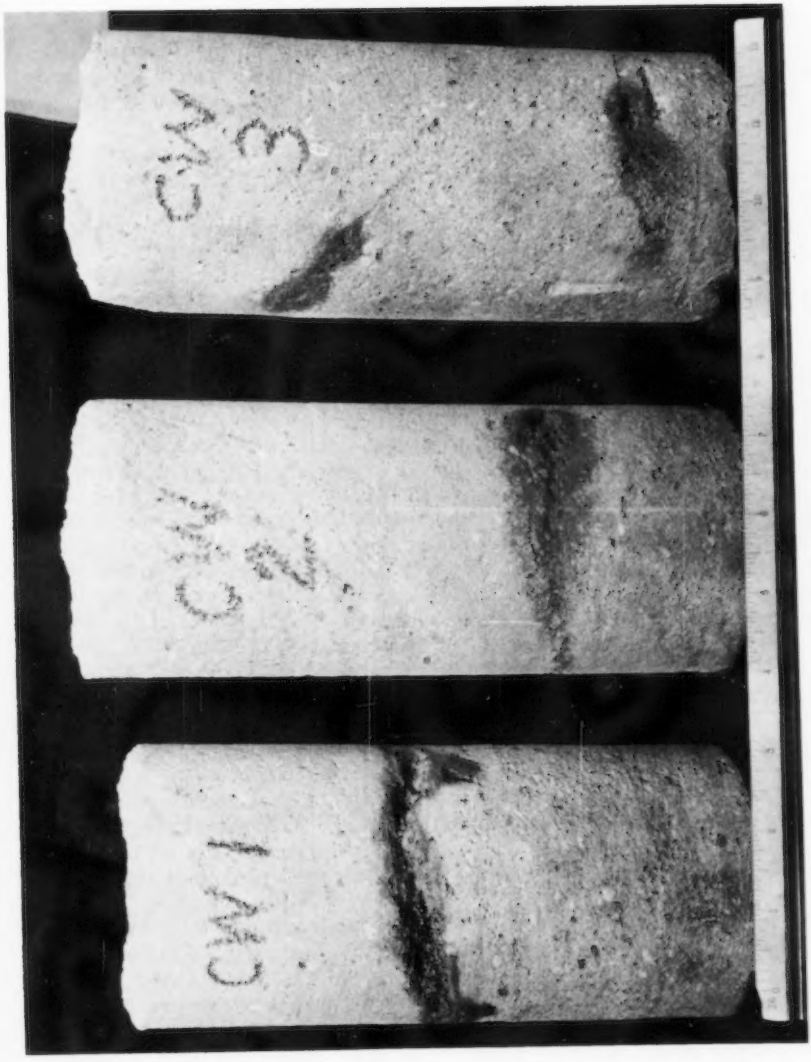

Fig. 2. Cores Taken from Counterweight Slope.

Form work was started from both ends of the structure. The pouring of concrete alternated irregularly between the launcher slope side and the counterweight side. Floor slabs and walls were built prior to pouring of the launcher and counterweight slab portions of the main structure. The steps and curbs on the counterweight slope of the cellular structure were formed with movable steel forms which cast eight steps each.

All concrete placed in the main structure was mixed on the site in a self-propelled 1-cu. yd. mixer. Sand and aggregate were mixed at the batching plant in Azusa, California, and hauled to the mixer by trucks, a distance of approximately 7 miles. Cement was added to the mixer by the sack, and water was automatically measured and added into the mixer.

In general, the concrete was poured in sections of about 50 cu. yd. The concrete was placed in the forms with a bottom dump, 1-yd. bucket, and a crane. Approximately 2140 cu. yd. of concrete were poured in this manner. A view of the form work for the cellular structure and partially completed counterweight slope is shown in Fig. 3.

Launcher Slab

The launcher slab below the main structure serves the primary purpose of supporting and anchoring the rails for the carriage. This slab was poured directly on the rough surface of the rock foundation.

Poured concrete was specified for the launcher slab because of the poor gunite obtained on the counterweight slab and because the launcher slab presented more difficult construction problems, such as heavier reinforcement and difficult working conditions on the 45° slope. Another factor which was considered was the importance of obtaining bond between the concrete and the main rail anchor bolts which must resist heavy uplift forces.

The initial excavation for the slab was done using a 2-yd. dragline from a bench cut near the top of the slope. Benches and steps were cut into the 45° slope using pneumatic tools. All material excavated, approximately 5000 cu. yd., was dumped into the lake at the toe of the slope. Final surface cleaning was done by hand labor and sluicing before pouring the slab.

In general, the principal reinforcement consisted of 1 1/4-in. square bars on 6-in. centers in the top and 1-in. round bars on 6-in. centers on the bottom placed transverse to the slab. Longitudinal reinforcement in general consisted of 1-in. round bars on 16-in. centers, both top and bottom.

The lower mat of reinforcing steel was fitted generally to the shape of the slope. The upper mat was set to specified grade. Both mats were supported by reinforced steel legs welded to the mat with the lower ends set in crevices in the rock. Where possible, the mats were tied to steel dowels previously grouted into the slope.

The launcher slab was formed with a movable steel form which was built by the contractor for this specific purpose. The structural steel form consisted of a channel-shaped steel face plate backed by steel beams and channel reinforcement with wheels at the four corners. A view of the form is shown in Fig. 4. The assembly was rolled up the slope on rails set on heavy timber falsework just beyond the side limits of the slab. Holes were drilled in the face plate for the accurate placement of the launcher rail anchor bolts.

To move from one pour to the next, it was necessary to lift the form off the anchor bolts. This was done with hydraulic jacks mounted near the four wheels. The jacks were also used to set the form to accurate grade before anchoring it to the steel mat.

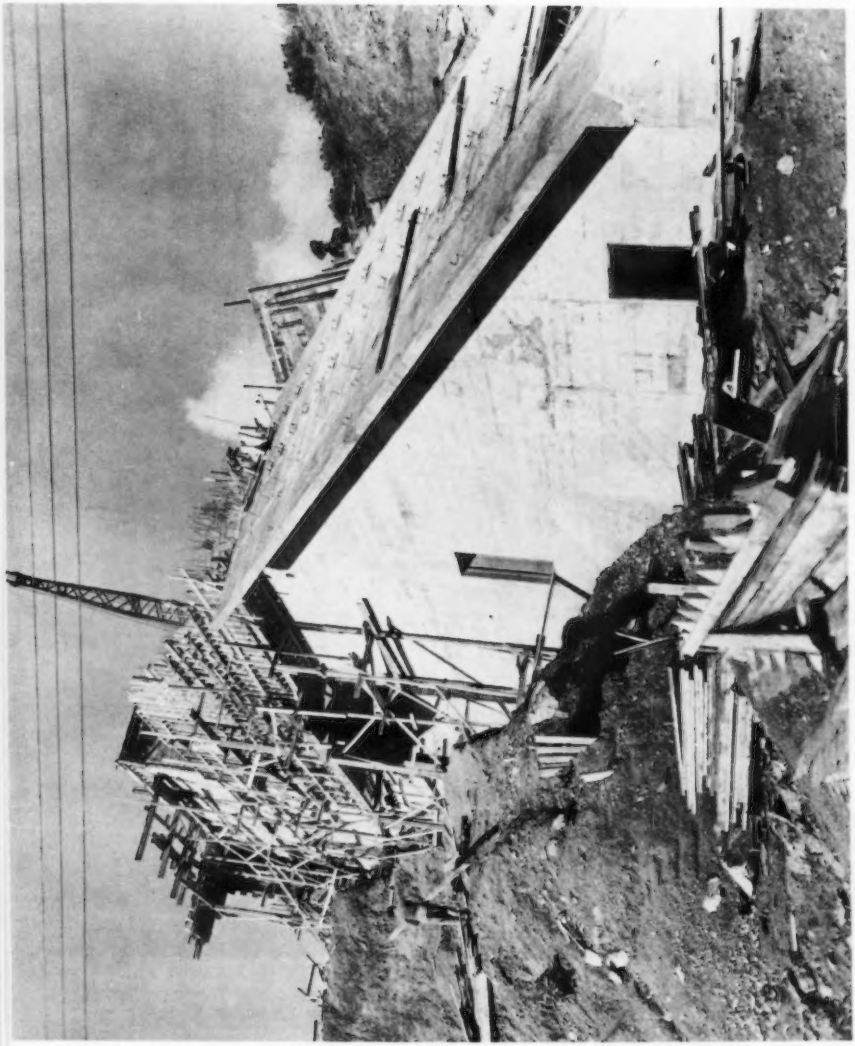

Fig. 3. Partially Completed Cellular Structure on Counterweight Side of Main Structure.

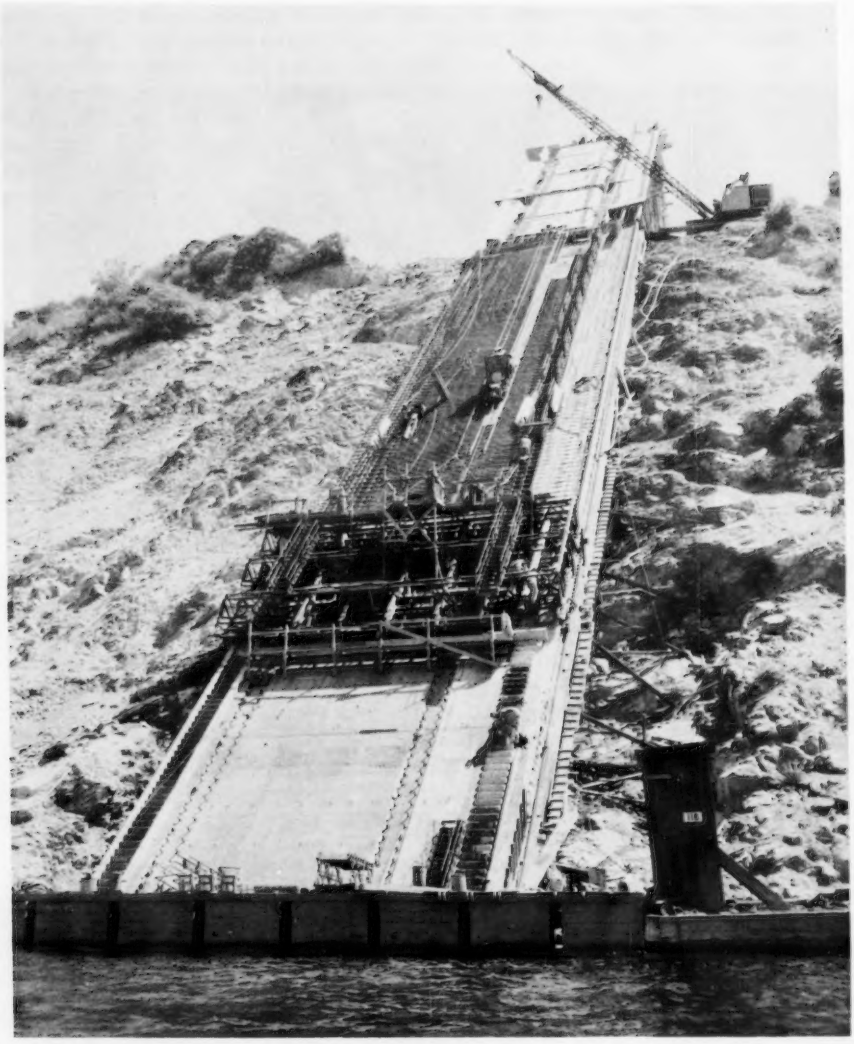

Fig. 4. The Launcher Slab During Construction Showing Reinforcement and Movable Form.

To insure exact spacing of the bolts, the lower line of bolt holes on the form were placed over the upper line of bolts in the previous pour. This overlapping also served as a good grade control for the bottom of the form. The form was set to line with a transit before each pour. The form was pulled up the slope by the tagline of a crane.

Steps, curbs and launcher rail indents were also cast by the movable form. The form, which poured a 25-ft. section of slab, was moved, set, and the concrete placed in a period of two days.

A 1-cu. yd. concrete mixer was set on a bench at the top of the slope. A steel car of 1-cu. yd. capacity was set on rails which were attached to the upper mat of slab reinforcement. The car was moved up and down the track by a winch which was anchored to the top of the main structure at elevation 1387.

Concrete was mixed and poured into a 1-cu. yd. bottom dump bucket. The bucket was swung by a crane over to the ramp car into which the concrete was dumped for transport to the pour. The car discharged into sheet metal troughs for lateral distribution at the pour site. Approximately 1640 cu. yd. of concrete were poured by this method. The slab had a minimum thickness of 4 ft.

The contractor chose to use calcium chloride as an admixture to the concrete on the launcher slope to accelerate setting. The average mix used was in a 1:2.4:3.3 proportion by weight with 8 lb. of calcium chloride added per batch.

Special rails for the carriage were anchored to the launcher slab by the previously placed 2-in. anchor bolts and grouted in place. These rails were heavy weldments designed to provide running surfaces for the dual wheels of the carriage and 7-in. pin holes for the locking pins of the carriage. The rails were loaded on a barge along with a crane and then moved to the bottom of the launcher slope. The two bottom rails were set on the anchor bolts by the crane. The remaining rails were placed one at a time by a pneumatic-tired car that was built so as to straddle the anchor bolts for one rail. The car was equipped with chain hoists for raising and lowering the rails; it was moved up and down the launcher ramp by a winch.

With survey control by the survey crew, the contractor juggled the rails up and down the slope with jacks, come-alongs, and shims until they were properly set. After final alignment, the contractor placed stiff grout under the rail base edge and wet grout under the center portion of the base plates which embedded shear lugs welded to the underside of the rail base.

Steel Structures of the Variable-Angle Launcher

Barges

The two barges which support the connecting bridge were fabricated at the contractor's shops using all-welded construction. The barges were 60 ft. long, 35 ft. wide, and 12 ft. deep and weighed 67 tons. Longitudinal and transverse bulkheads divided the interior into 12 compartments.

The sides, ends, and deck of the hull as well as the bulkheads were constructed of 1/4-in. plate and the bottom was constructed of 5/16-in. plate. The bottom and end plates were stiffened with ST 9 WF 23.5# on 2 ft. 9 in. centers, the side plates with 6 x 4 x 3/8 angle on 2 ft. 9 in. centers, and the deck with 5 x 3 1/2 x 5/16 angle on 2 ft. 9 in. centers. One-half in. plate

was fabricated into part of the deck to receive the connecting bridge anchor seats.

Steel plate was cut with a torch to the required predetermined sizes to be fitted together and welded into the required size to form the bottom, sides, and ends of the hull. The pieces were tack-welded together on the shop floor prior to completing the welds with automatic welding machines. Stiffeners were then welded to the built-up sheets.

After the bottom of the hull had been shored up in the yard, the bulkheads forming the compartment were welded into place. The sides and ends were then welded to the bottom and to the bulkheads. The deck which had been previously assembled was then lowered into place and welded. Hand arcwelding was used during assembly and sequence-welding was used to reduce distortion.

The exteriors of the barges were painted with hot-applied bitumastic enamel. A long-lasting protective coating had to be applied to the exterior of the hull to reduce maintenance to a minimum.

The interiors of the barges were painted with one coat of red lead primer and two coats of cold applied bitumastic paint. The interior of each compartment can be inspected periodically as access is provided to each compartment through man holes in the deck.

It was the intention of the contractor to transport the completed barge to the site by truck. However, load limitations of a highway bridge and restrictions offered by narrow canyon walls made it necessary to cut the barges in half. The 30 x 35 ft. half sections were transported to an erection area located on the reservoir about a mile up stream from the Variable-Angle Launcher site. A view of a half section of the barge during transportation is shown in Fig. 5. The halves of the barges were then installed on ways which had been built by the contractor for launching the barges. A field-weld transverse to the bridge amidship was used to connect the two halves. Touch-up of the painting in the area of field-welding was made prior to the launching. Completion of the deck work was made after launching.

Connecting Bridge

The connecting bridge is a 95-ft. span all-welded structure connecting the two barges and supporting the outer end of the launcher bridge. The connecting bridge contains about 38.5 tons of structural steel.

The centerline distance between bottom chords is 20 ft. 9 1/8 in., and the distance between top chords is 4 ft. The bottom chord is 95 ft. long, and the top chord is 22 ft. long.

The lower chord and upper chord members consisted of 14-in. WF sections while the diagonals were 10-in. WF sections. Lower chord transverse diagonal members were 12-in. WF sections and the upper chord bracing was fabricated from 1/2-in. steel plate with 3/8 x 3 3/4-in. plate stiffeners on 2 ft. 3 in. centers.

The trusses were fabricated in the contractor's shops in three sections, consisting of a 34-ft. center section and two end sections of 30 1/2 ft., and were erected and field-welded in place on the barges at the erection area.

In general, members which were under 3/8 in. in thickness were butt-welded together with the members beveled at 60° on one side only. Members 3/8 in. and over were beveled at 60° on both sides. All beveling was done with a cutting torch.

Fig. 5. A Half Section of the Barge on a Trailer as it is Being Transported to the Erection Site.

The centerline of the truss members was scribed on the steel floor in the contractor's shop. Wide flange sections were cut to size and the flange cut off for joint flaring. The sections were then tack-welded to the floor. Plates which had previously been cut and rolled to the correct curvature were tacked into place. The sections were then welded together except at the predetermined joints in the chords and diagonals which were left for field-welding at assembly.

Wide flange sections were cut to size and welded together forming X-shaped bracing for the lower diagonal system, the vertical diagonal system, and the inclined portal system. At the intersection of the wide flange members curved filler plates were welded to the flanges of the members.

After welding had been completed, the various sections were wire-brushed and given a shop coat of red lead primer.

Field assembly started at the site by having the two barges pulled up along side of each other. The first 30 1/2-ft. section of truss was set by a crane in the two supports on the one barge and bolted to them. The center 34-ft. section was then set on shoring on the second barge and after alignment tack-welded to the end section. After setting and bolting the end section of the other truss to the barge, temporary bracing was welded to both trusses to maintain alignment. The lower chord horizontal diagonal bracing and the vertical diagonal bracing were then set into place and tack-welded to the one truss. The center section of the other truss was set into place and after alignment tack-welded onto the structure. After carefully checking alignment in all directions, the members were completely welded together. A view of the connecting bridge during field fabrication is shown in Fig. 6.

After completion of the welding, the barges were moved apart and the two remaining end sections of the trusses set on shoring and welded to the center sections. The end bracing section and the remainder of the lower chord bracing was then welded to the structure. The barges were pulled apart to the required spacing and the end section bolted down to their supports. The welds were wire-brushed and primed with a coat of red lead primer and the whole structure sprayed with a coat of aluminum paint.

Launcher Bridge

The launcher bridge is an all-welded structure of 300 ft. span; it is 22 ft. wide and 35 ft. deep. The main trusses are 12-panel Pratt type and the transverse frames at each panel are three-story, two-bay, rigid frames. Conventional X-bracing was used in the horizontal planes of the upper and lower chords. The centerline vertical members as well as the web members of the trusses were stabilized at the third points by longitudinal stringers.

Members were mostly 14-in. WF sections or equivalent sections made by welding three plates together. These welded sections were supplied at the contractor's option because of long unavailability of rolled shapes. Steelwork was fabricated in the contractor's shop and transported to the erection area on the shore of the reservoir. Approximately 251 tons of structural steel were fabricated into the launcher bridge exclusive of deck grating and railings.

Tolerances for erection of the launcher as given in the specifications were as follows:

"a. In the total length of either truss, a horizontal tolerance of one inch will be allowed with reference to a vertical plane connecting the centerlines of the end verticals of the truss, and a vertical tolerance of one in. will be

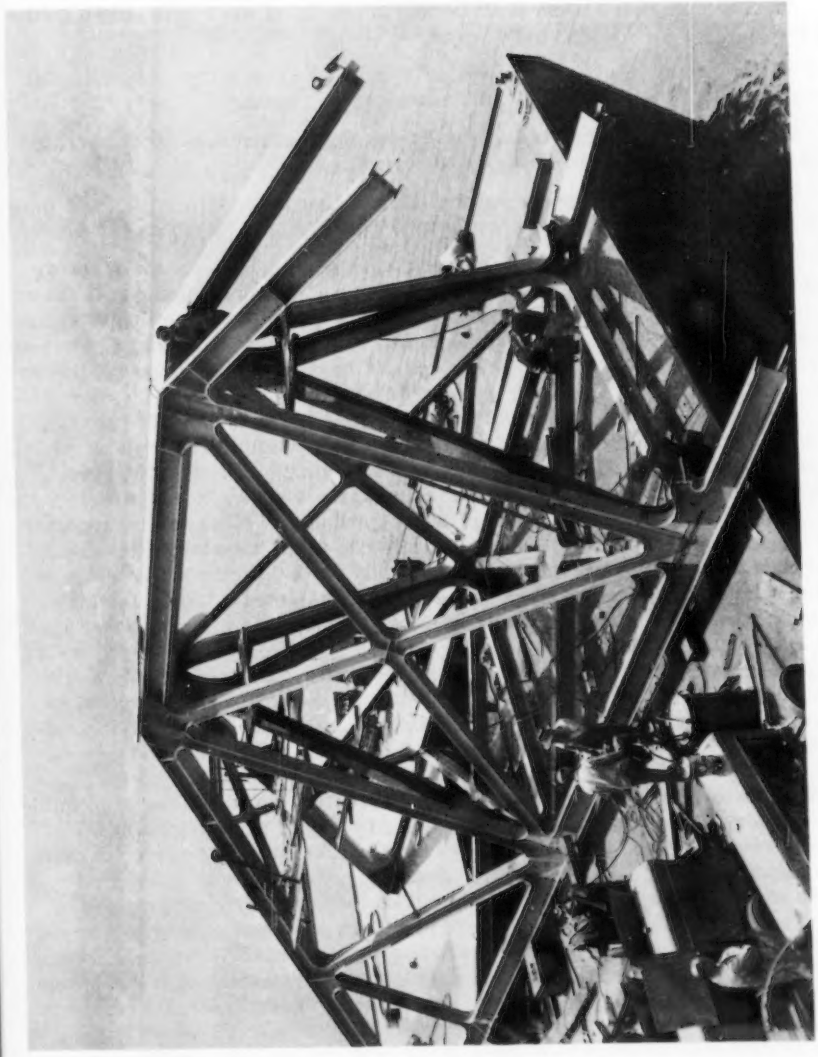

Fig. 6. The Connecting Bridge Being Assembled on the Barges at the Erection Site.

allowed with reference to a line between ends of the truss and corresponding to the designed camber of the truss. However, local alignment shall not vary more than 3/8 in. from a longitudinal line, to specified camber, connecting two corresponding points 50 ft. apart, or from a vertical plane through corresponding points 50 ft. apart.

"b. The completed truss shall be within one in. of the length shown on the drawings.

"c. Any point on one truss shall be within 1/2 in. of a line perpendicular to the plane of the other truss at a corresponding point.

"d. Distance between top and bottom chords of each truss shall be within 1/2 in. of the dimensions shown on the drawings.

"e. The horizontal distance between truss chords shall be within 1/4 in. of the dimensions shown on the drawings."

The first phase of shop work consisted of the fabrication of the frames. The 14-in. WF sections were torch-cut to length and assembled on the floor of the contractor's shop. The lower transverse member of the frame was not welded into the assembly, but was welded into the lower chord or deck assembly. During welding the members were held in alignment by tack-welding to the floor.

The second phase consisted of fabricating the lower chord. The lower chord or deck structure was assembled on a timber falsework built up so as to include the required camber. The deck structure consisted of the lower chord of the trusses, the lower transverse frame member, the X-bracing, and the girders for the decking. Fabrication consisted of tack-welding together the 14-in. WF sections of the truss chord. The lower member of the frame was then tack-welded to the chord section and the X-bracing tack-welded in. After checking alignment and camber, final welding was started. During welding careful check of alignment was made to keep the fabrication within the allowable tolerances.

During the welding of the lower chord structure, radiographing of welds was started. A number of welds were found which were not satisfactory because they contained slag deposits or hairline cracks, or because full penetration of weld was not accomplished. All deficient welds were chipped out and rewelded. A cross section of one of the bad welds is shown in Fig. 7.

To improve the welding, a record was kept of the work done by each welder. Also, the inspector approved the back chipping of each weld before the welder could continue. Radiographs of welds made after this sytem was put into effect indicated no poor welds. Apparently, welders will make good welds when they know that their work will be inspected by radiographing.

After the full 300 ft. of lower chord structure had been welded, it was cut into approximately 50 ft. sections for transportation to the erection area.

The third phase of shop work consisted of cutting to size the WF sections which comprise the upper chord, vertical diagonals, and upper X-bracing members.

All fabricated members were given one coat of red lead primer prior to transportation to the erection area by truck and trailer.

At the erection area the lower chord sections were set again on a timber falsework with built-in camber and tack-welded together. The transverse panels were lifted into place individually by a crane and held until side

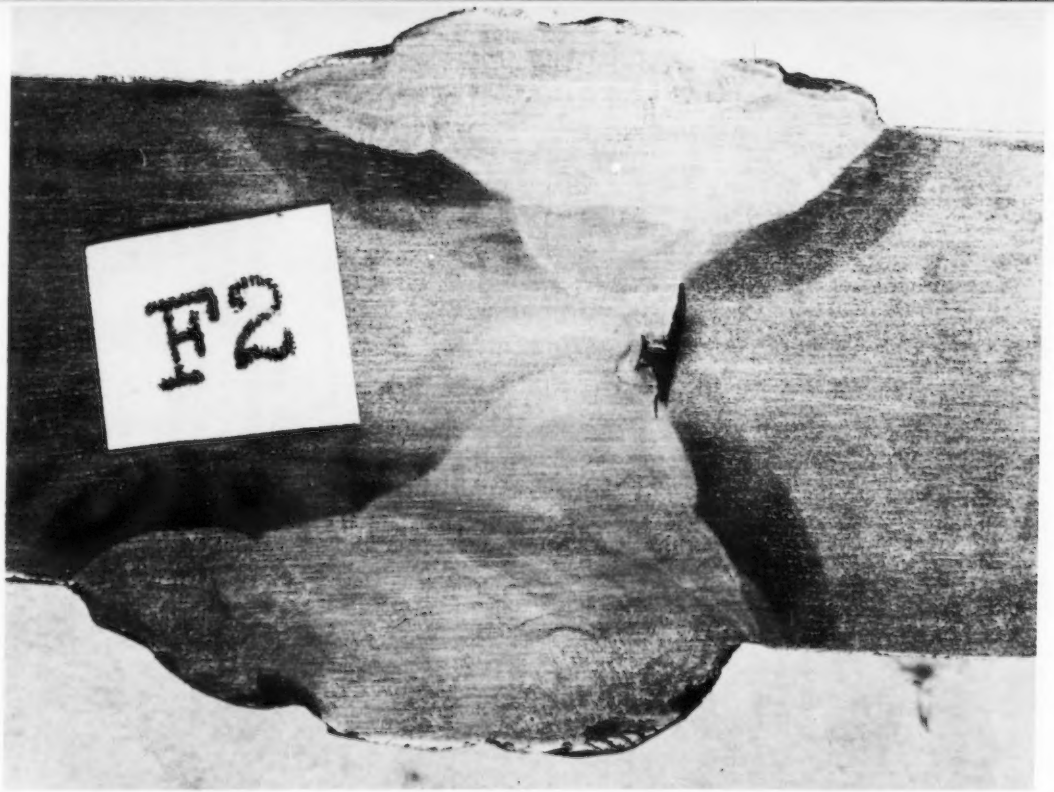

Fig. 7. A Cross Section of a Weld Cut Out of a Launcher Bridge Member. Weld was not Back Chipped and Poor Penetration Resulted.

diagonal members and other braces were tack-welded sufficiently to hold the panels rigid.

Succeeding panels, diagonals, and top chord were set in place and tack-welded together. After checking alignment and fabrication tolerances, the welding together of the various members was started. During the welding process, 12 gasoline-driven electric arc-welding machines were being used. Fig. 8 shows how the various members were assembled into the bridge.

After the main structure was welded, the deck grating and movable stairway were installed. As the welders progressed, painters followed with a field coat of red lead. When the steel erection and red lead painting were completed, the entire structure was sprayed with the final coat of aluminum paint.

The launching tube and the air tank were then installed in the bridge. Upon arrival at the erection site, the tank, which weighed approximately 45 tons, was lifted from the trailer bed by a 60 ton speedcrane and a truck crane and set on the ground at the breech end of the launcher bridge.

Two longitudinal erection beams and several bracing members were welded between panels P-0 and P-1 of the bridge as supports for the tank. Three cranes lifted the tank to the entrance section of panel P-0, and a bulldozer with a line reeved through a snatch block at P-1 and tied to the tank pulled the tank part way into the bridge. Then the cranes moved in closer and swung the tank to the required position.

The transportation of the completed bridge to the launcher site was accomplished by floating the bridge down the lake on barges. The timber falsework was removed by jacking up the bridge, and the bridge was then lowered onto two sets of rollers. The forward set was laid at a skew angle so that the bridge could be turned through an angle of about 20° in order to bring the lower end panel P-12 over the connecting bridge pillow blocks. When the bridge had been rolled into the required position, ballast water in the barges was pumped out to bring the pillow blocks up to the lower pivot pins. After the launcher bridge had been seated on the connecting bridge, the shore end of the launcher bridge was rolled towards the lake to pick up the load at the panel points P-3 and P-4. A pontoon barge consisting of 156 pontoons was moved under the launcher bridge between the connecting bridge and the shore. Timber cribbing had been built up in the center of the barge to a height of about 25 ft.

When the bridge had been rolled out so that panels P-3 and P-4 were over the cribbing, the lake level was raised about 2 ft. by discharging water from San Gabriel Canyon Dam No. 1 into Morris Dam lake to lift the shore end of the bridge off the rollers. The bridge was then floated down the lake to the launcher slope, a distance of approximately one mile. Fig. 9 is a view of the launcher bridge during transportation.

It was then necessary to raise the lake level about 17 ft. to bring the horizontal pivot casting to the elevation of the pivot platform of the support carriage. The support carriage had previously been set on the launcher slope, as is described later.

When the bridge reached the launcher slope, it was slowly jockeyed into place on the support carriage. The heavy weldment which transmits the longitudinal and transverse loads to the carriage had been suspended below the launcher bridge at panel point P-0 during transportation. After the bridge was in the correct position, the weldment was lowered onto the carriage and welded to it.

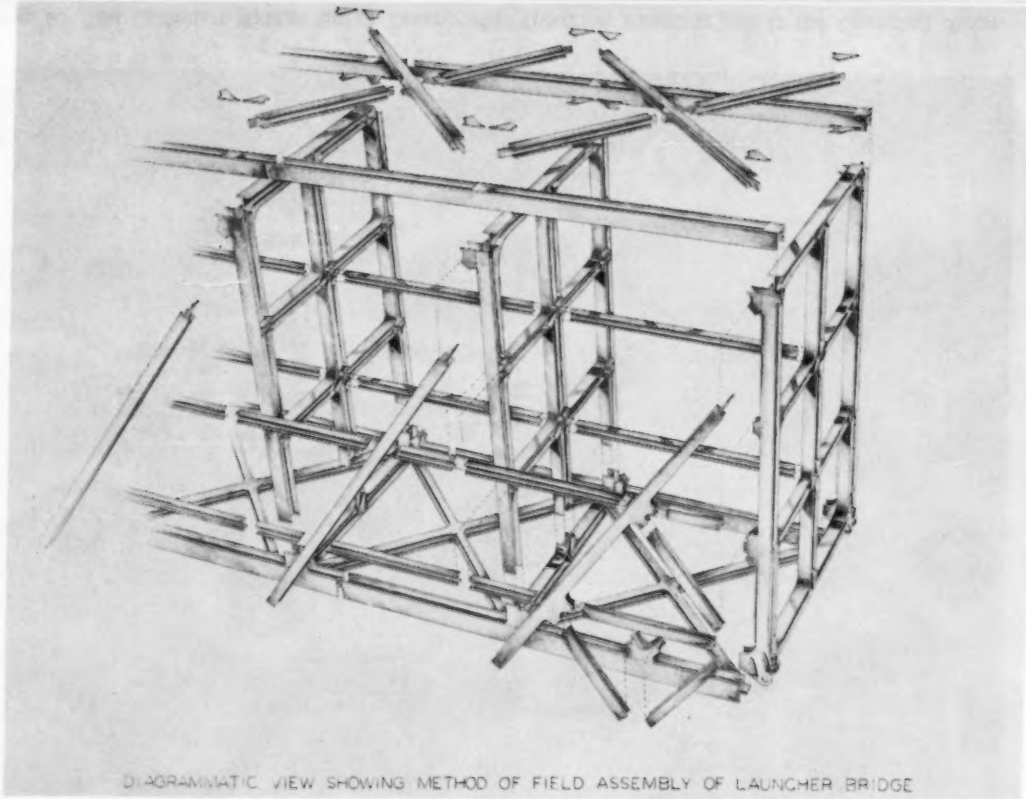

Fig. 8. Method of Field Assembly of the Launcher Bridge.

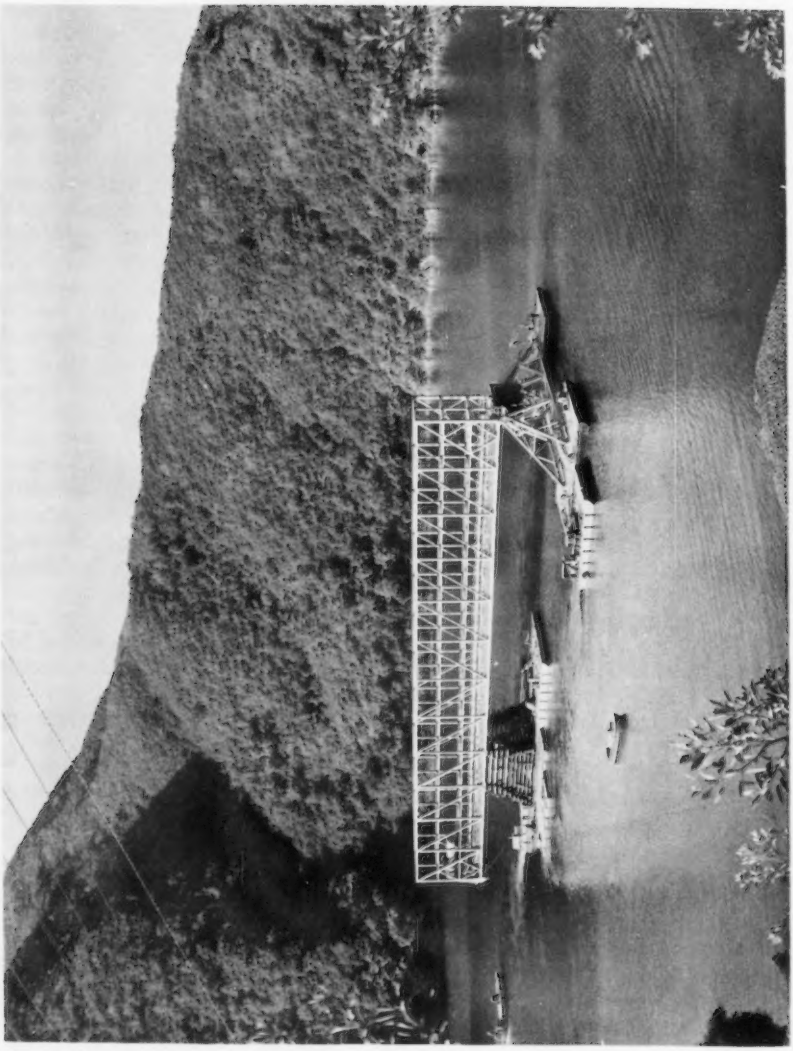

Fig. 9. The Launcher Bridge Being Transported from the Erection Site to the Launcher Slope.

During the welding of the weldment to the carriage, windstay cables were reeved, giving an outboard anchor against lateral movement of the bridge. The pontoons of the temporary barge were filled with water to lower it enough to float from under the bridge.

Counterweight Car

The car operates on a 30° slope and acts as a counterbalance for the launcher bridge. It consists of a steel frame or chassis mounted on 20 railway-car wheels and a concrete body. The counterweight car is attached to sixteen 2 1/8-in. steel cables which reeve through the main drive equipment and terminate at connections to the bridge support carriage.

The 50 ft. x 10 ft. all-welded counterweight car chassis was fabricated in the contractor's shop. The wheels, axles, and journal boxes were mounted on the chassis in the shop. This assembly was transported to the launcher site by truck and unloaded by a 60-ton speedcrane that was located on the west side of the structure. During the process of setting the car chassis on the rails, the crane upset and dropped the car to the ground on the east side of the slope. The car broke loose, rolled down a ravine and plunged into the lake. Navy divers later located the car in 105 ft. of water; it was almost completely buried in mud.

With the aid of blocks and tackle attached to the connecting bridge mounted on the two barges, the chassis was retrieved from the mud and towed to the erection area. It was then cut in half with an acetylene torch and hauled back to the contractor's plant for clean-up and minor repairs.

Later, the car was returned to the counterweight ramp where it was installed on the rails in two pieces. The two sections were then welded together. The car was held in position on the rails by a steel bumper anchored to the concrete structure.

At the forward end of the chassis, the drawbar assembly, a heavy weldment, was welded to the chassis. The reinforcing steel mat for the concrete body which had been fabricated in the contractor's shop was then welded to the drawbar assembly. This reinforcing mat consisted of 17 1-in. square bars running longitudinally and 5/8-in. round bars welded at right angles to the 1-in. bars.

Plywood forms which had been prefabricated in panels were secured to the car chassis. Concrete poured into these forms made the car body and the interior compartment for the ballast block. The steel chassis served as the bottom form for the pouring of the concrete.

The heavy concrete for the car body was made by replacing part of the rock aggregate with scrap nuts, bolts, and punchings. The concrete mix was designed to include 3200 lbs. of scrap steel per cu. yd. with seven sacks of cement thus produced a theoretical density of 225 lbs. per cu. yd. The concrete was mixed in a 1/2-yd. mixer, and all aggregate and scrap was weighed prior to being placed in the mixer. The concrete was transferred from the mixer to bottom drop buckets for pouring into the forms.

Blocks of heavy concrete poured in wooden forms provided additional ballast for the counterweight car. Two sizes, 1 ft. 0 in. x 1 ft. 6 in. x 3 ft. 6 in. and 0 ft. 8 in. x 1 ft. 0 in. x 2 ft. 6 in. were poured. The concrete mix was designed to include 5400 lbs. of scrap steel per cu. yd. with 5.5 sacks of cement per cu. yd., and a maximum of 6 3/4 gal. of water per sack of cement thus produced a theoretical density of 270 lbs. per cu. yd.

Carriage

The carriage is a complex welded structure which supports the breech end of the launcher bridge. It can be moved up or down the slope and locked to the rails with hydraulicly actuated pins. The carriage consists of a heavy structural-steel space framework on which is mounted the launcher bridge support deck, compressor platform, revolving platform, fixed upper platform, and four wheel assemblies. Each wheel assembly contains four standard railway-car wheels complete with Timken roller bearing journal boxes and 7-in. locking pins. The pins are located 33 ft. 8 3/4 in. apart along the longitudinal axis of the carriage.

The launcher bridge support deck, compressor platform, revolving platform, fixed upper platform, and wheel assemblies were fabricated as units in the contractor's shop. Extreme care in alignment and welding sequence was required in the fabrication of the wheel assemblies and the launcher bridge support deck. The locking pin holes through the two plates of the wheel assemblies were line-bored to maintain the center of the holes directly opposite each other.

After the units were fabricated in the shop, they were cleaned and sprayed with one coat of red lead primer and then transported to the erection site.

The carriage was assembled at the erection area. Close inspection and precise workmanship were needed in order to keep within the tolerances allowed. The relation of pin holes to each other in the wheel assemblies was one of the most critical factors to control. They had to be correctly spaced because no longitudinal adjustment of the rear pins was provided. Any appreciable error in pin spacing would make it impossible to insert the pins into the holes in the track.

At the erection site the contractor poured four concrete footings on which were bolted two rails similar to the rails on the slope. These rails contained the pin holes which spaced the wheel assemblies. The four wheel assemblies were set on the rails and the pins put through the holes to provide a lock for the assemblies; the remainder of the carriage was then assembled. Fig. 10 is a view of the carriage during erection. After the launcher bridge support deck, the compressor platform, and the connecting members had been erected on the wheel assemblies, the completed structure was sprayed with one coat of red lead and a final coat of aluminum paint.

Transportation to the launcher slope was accomplished by mounting two rails, similar to those on which the carriage was erected, on a pontoon barge with ends extending beyond one end of the barge. Two 7 1/2-ton gasoline winches were welded to the barges outside the gage of the rails. The overhanging ends of the barge rails were secured to the lake-end of the erection rails by pins and the assembled carriage pulled aboard the barge. The carriage was then transported down the lake to the foot of the launcher slope.

The overhanging ends of the barge rails were pinned to steel anchor blocks previously set on concrete bases at the bottom of the main launcher rails. A 50-ton block was anchored up the slope to each rail and one on each upper wheel assembly. A single cable was reeved from one winch through the four blocks and to another winch, thus providing adequate drum capacity. The pull of the two winches was utilized to draw the carriage onto the launcher rails, where it was anchored with the locking pins.

The contractor completed fabrication of the carriage on the slope. This work included the attaching of the shop-fabricated upper fixed platform, the

Fig. 10. The Carriage During Field Assembly at the Erection Site.

bridge shoe arc rails, the framework for the overhead crane, and the hydraulic and lubricating systems.

The two arc rails which support the launcher bridge required accurate setting, so that the top of the two rails would be in the same horizontal plane. After considering a number of methods, it was decided to bring the rails to grade by means of adjusting screws through the track base and then to fill up any space between the rail base and the top of the carriage platform with a low melting point alloy.

Rigging

Rigging of the various items of the Variable-Angle Launcher was let to a separate contractor. Rigging items were numerous, and only those of major magnitude are described in this paper.

In order to place the main drive hoist unit on the top platform of the concrete structure of the Variable-Angle Launcher, elevation 1387, the contractor erected a 90-ft. gin pole on the west area at elevation 1340. The load line fed into a heavy skid-mounted, gasoline-driven hoist set that was anchored at the east entrance to the arch at elevation 1340. The gin pole was guyed to both slopes of the structure and to heavy concrete blocks set on trailers.

The main hoist frame, weighing about 40 tons, was lifted over the top of the concrete structure and set on rollers. The frame was rolled into place, lowered onto the anchor bolts, and set to line and grade. The forward drum was raised and set in place on the frame. Then the sixteen 2 1/8-in. cables were draped across the drum and frame and down the two slopes. The aft drum was then raised and set in place on the frame and the cables from the counterweight end wrapped over this drum. Finally the top drum was raised and mounted and the counterweight ends of the cables brought over and dropped down the counterweight ramp into position for assembly to the counterweight car.

The base of the frame was grouted into place with a patented non-shrink cement. The gear reducer, magnetic brake, and motor were then raised into place, coupled, aligned, and grouted.

For photographic purposes the launching range is equipped with an overhead cable system. The main 3/4-in. cable on which the camera car rides is attached to a tower located on top of the concrete structure and extends 1800 ft. down-range to a Y-connection supported by two 3/4-in. cables 1100 ft. long which anchor to winches tied to the canyon walls by concrete and steel dead-men. Materials for the anchorage were carried up the steep slopes on the backs of laborers. After setting the dead-man anchors, the winch frames were lined and tied to the anchors. The cables were attached to the towers and anchor winches, the free ends pulled to a barge on the lake, the Y-joint attached, and the system pulled to line and grade by use of the anchorage winches.

The Variable-Angle Launcher was dedicated on 7 May 1948. Since that time it has served as an important testing device in the field of underwater research for the U. S. Navy.

ACKNOWLEDGMENTS

The construction was under the jurisdiction of the Bureau of Yards and Docks of the United States Navy, with Captain H. L. Mathews acting as Officer

in Charge of Construction, and Commander C. E. Langlois as Resident Officer in Charge of Construction. The design was the responsibility of the Development Engineering Section of the Underwater Ordnance Division of the U. S. Naval Ordnance Test Station, China Lake, California, (Pasadena Area). W. H. Saylor, Head of Underwater Ordnance Division, and J. H. Jennison, Chief Engineer, were in charge of design. Consultants employed on the project were: Coast Marine Engineering Company; F. J. Converse, Consulting Foundation Engineer; Frank G. Denison, Jr., Naval Architect; V. P. Pentegoff, Consulting Geologist; Quinton Engineers, Ltd.; and N. D. Whitman, Jr., Consulting Structural Engineer. The General Tire and Rubber Company of California was prime contractor. Major sub-contracts were awarded to United Concrete Pipe Corporation for steel structures and to Norman I. Fadel for concrete structures.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1113 is identified as 1113 (HY6) which indicates that the paper is contained in the sixth issue of the Journal of the Hydraulics Division during 1956.

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APRIL: 1196(EM2), 1197(HY2), 1198(HY2), 1199(HY2), 1200(HY2), 1201(HY2), 1202(HY2), 1203 (SA2), 1204(SM2), 1205(SM2), 1206(SM2), 1207(SM2), 1208(WW1), 1209(WW1), 1210(WW1), 1211(WW1), 1212(EM2), 1213(EM2), 1214(EM2), 1215(PO2), 1216(PO2), 1217(PO2), 1218 (SA2), 1219(SA2), 1220(SA2), 1221(SA2), 1222(SA2), 1223(SA2), 1224(SA2), 1225(PO)[c], 1226 (WW1)[c], 1227(SA2)[c], 1228(SM2)[c], 1229(EM2)[c], 1230(HY2)[c].

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AUGUST: 1330(HY4), 1331(HY4), 1332(HY4), 1333(SA4), 1334(SA4), 1335(SA4), 1336(SA4), 1337(SA4), 1338(SA4), 1339(CO1) 1340(CO1), 1341(CO1), 1342(CO1), 1343(CO1), 1344(PO4), 1345(HY4), 1346(PO4)[c], 1347(BD1), 1348(HY4)[c], 1349(SA4)[c], 1350(PO4), 1351(PO4).

c. Discussion of several papers, grouped by Divisions.

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